THE

GEOLOGICAL MAGAZINE

NEW SERIES. DECADE VI. VOL. III.

No. IV.—APRIL, 1916.

ORIGINAL ARTICLES.

I.—Two large Obsidianites from the Raffles Museum, Singapore, and now in the Geological Department, F.M.S.

By J. B. Scrivenor, M.A., F.G.S.

(PLATE VII.)

SOME years ago I was asked to look through a collection of geological specimens in the Raffles Museum, Singapore, and found in a drawer two exceptionally large obsidianites. They were not labelled, and nothing could be ascertained about their history, but an assistant in the Museum said he thought they might have come from Kelantan, a State on the east coast of the peninsula. The weights of the two obsidianites were 464 and 316·4 grams. The former and larger of the two was entrusted to a local firm to cut in half, with the result seen in Pl. VII, Fig. 1. The photograph, nevertheless, shows that there is a group of vesicles in the centre. The photographs, which are natural size, also show that there is nothing unusual about the surface of these specimens (Pl. VII, Fig. 2).

An analysis of a portion of the larger specimen has been carried out by Mr. C. Salter, Chemist in the Geological Department, F.M.S. In May, 1915, Dr. Mueller (Geol. Mag., 1915, pp. 206–11) described under the name of 'Tektite' obsidianites from near Tutong, a dismal, crocodile-infested station in Borneo that I also have had the misfortune to visit, and gave an analysis by Dr. Hinden (op. cit., p. 209). The close agreement in composition of the Singapore specimen is noteworthy, and is shown in the following table (p. 146), together with some of the analyses quoted in a recent paper by Mr. C. G. Thorp ("A Contribution to the Study of Australites," Journ. W. Australian Nat. Hist. Soc., vol. v, pp. 1–26, 1914), and others of obsidian from Iddings' *Igneous Rocks*, and from a description by Dr. Prior of rocks from British East Africa ("A Contribution to the Petrology of British East Africa," Min. Mag., xiii, pp. 245, 247, 1903). The more important constituents only are given, and the analyses of 'Australites' and 'Moldavites' are selected from Mr. Thorp's paper to show the extreme ranges of silica percentage. No. 12 is described by Dr. Prior as "phonolitic obsidian"; No. 13 as "obsidian glassy soda-rhyolite".

The range in silica percentage in obsidianites is shown by the analysis to be large. Dr. Mueller mentions the difference in the composition of obsidianites from that of obsidians. There is certainly a marked difference compared with the U.S.A. obsidians, but when one compares them with the East African rocks, which differ chiefly in the preponderance of Na_2O over K_2O, and considers that a glass

having the composition of some of the 'adamellites' or 'granodiorites' would have a composition even nearer that of the obsidianites, the chemical difference that, I gather, Dr. Mueller deems evidence of the obsidianites not being of terrestrial origin, does not appear to be of great importance. A stronger objection to a terrestrial origin for these Singapore specimens is their weight. Pumice from Krakatoa

	Obsidianites.								Obsidian.				
	Singapore Museum.	Tutong.	Australites.		Billitonites.		Moldavites.		U.S.A.			British East Africa.	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
SiO_2	69·80	70·90	64·68	77·72	70·92	71·14	77·69	82·68	75·52	74·52	76·20	64·00	70·61
Al_2O_3	14·30	13·50	16·80	9·97	21·20	11·99	12·78	9·56	14·11	13·72	13·17	10·43	8·59
TiO_2	1·00	1·00	—	·86	—	—	—	—	—	—	—	·78	·15
FeO	5·65	5·47	1·01	3·75	5·42	5·29	1·45	1·13	·08	·62	·73	3·86	5·96
Fe_2O_3	·15	·32	6·57	·32	1·07	—	2·05	—	1·74	1·01	·34	6·30	2·52
MnO	trace	trace	·20	trace	·41	·32	—	·18	—	trace	·10	·37	·34
CaO	2·61	2·35	3·88	2·40	3·78	2·84	1·26	2·06	·78	·78	·42	1·45	·61
MgO	3·20	2·45	2·50	1·57	2·61	2·38	1·15	1·52	·10	·14	·19	·34	·07
Na_2O	1·16	1·46	trace	1·29	2·46	2·45	·78	·63	3·92	3·90	4·31	7·59	6·77
K_2O	1·90	2·17	4·01	1·96	2·49	2·76	2·78	2·28	3·63	4·02	4·46	4·59	4·46

has floated to the east coast of the peninsula, but the idea of these obsidianites having floated to the peninsula attached to masses of pumice is precluded by the absence of any pumice of similar composition; and one cannot admit that bodies of this weight could drift in the upper atmosphere any more readily than one can admit it of a rifle bullet. A cosmic origin seems the only possible explanation.

II.—Ball or Pillow-form Structures in Sandstones.[1]

By Bernard Smith, M.A., F.G.S.

THE structures described below occur in rocks of a rather monotonous and generally uninteresting type; namely in sandstones, interstratified with masses of shale and mudstone, exposed near the centre of the Berwyn Anticline in parts of Denbighshire. The necessity, however, of examining every exposure, incumbent upon the Surveyor, has led me to pay attention to detail, and especially to certain phenomena that would appear to be of world-wide occurrence in sediments of all ages.

Description of the Sandstones.

The sandstones are of both Llandilo and Bala age. Those of Llandilo age occur sparingly in a mass of scantily fossiliferous shales in the Llanrhaiadr-ym-Mochnant district, but become more important when followed eastward along the strike in the direction of Llansilin. In the same districts the Bala Beds are more prevalently sandy, and the strata are of a more regular character.

[1] With the permission of the Director of the Geological Survey.

1. *Llandilo Sandstones.*—In the west thick lenticles of sandstone, or masses of alternating lenticles and shales, occur at infrequent intervals, as at Llanrhaiadr, where one bed is as much as twenty feet in thickness. Farther east the beds of sandstone appear more frequently, and are often thicker than those in the overlying Bala, and sometimes of coarser type. They are well-developed near Moel y Gwelltyn, Gyrn Moelfre, Craig-yr-hŵch, and Foel Rhiwlas.

The sandstones are blue laminated gritty quartz-felspathic and slightly calcareous rocks, often weathering like an ashy sediment; whilst some beds are true 'ashy sandstones'. They contain pellets and pebbles of shale and mudstone, and in weathered specimens show brown or yellowish-red earthy inclusions. Like the Bala sandstones they contain white mica, which is clustered thickly along the ripple-marks. Although the prevalent type of rock is well-laminated, some of the coarser parts appear to be structureless. Drift- and current-bedding is fairly common. The constituent grains are angular and of two sizes, respectively about $\frac{1}{100}$ and $\frac{1}{300}$ inch in diameter.

2. *Bala Sandstones.*—These occur normally as beds averaging about 2 feet in thickness, with interstratified shales and shaly sandstones. The thicker beds are nearer 3 feet across, but in some places, such as Nant Engyll Quarry, Coed Garth Eryr, Llwyn Bryn Dinas, and Llangedwyn Hall, lenticular masses, like those in the Llandilo, occur up to 10 feet in thickness.

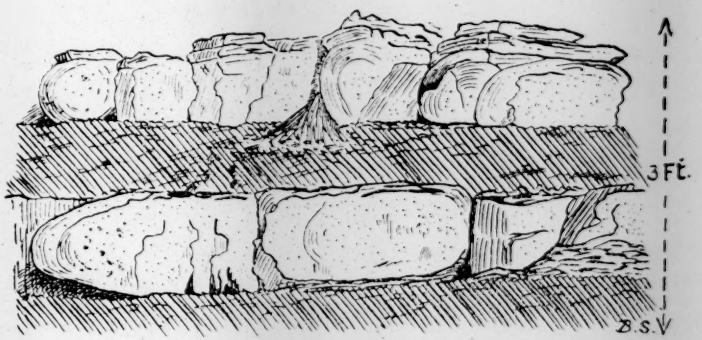

FIG. 1.—Ball and pillow-form structures in beds of sandstone between cleaved shales, in crag west of Moelfre, Llansilin.

When fresh the rocks are tough, blue, or blue-grey, fine-grained laminated micaceous sandstones, with many included laminæ of shale. They are fossiliferous and occasionally slightly calcareous, when they weather to rottenstone. Frequently they are ripple-marked and show drift- and current-bedding, the latter structure being most common in the more lenticular masses. They are less felspathic than the Llandilo sandstones, but contain some thin layers of ash and isolated crystals of felspar.

Pillow-form and Ball Structures.

In some sections, either natural or quarried, parts of the sandstone, interbedded either in similar sandstone or in shale, assume

a pillow-form (Fig. 1), ball-like, or semi-spheroidal habit. The spherical contours are usually developed on the undersides of projecting ledges of weathered sandstone as rounded lobes and curved surfaces, whilst occasionally they occur on the upper surfaces as well, when the rock becomes still more pillow-form in appearance. The spheroids are hardly ever completely developed. If they were they would average about 1 foot in diameter, with a maximum of 2 ft. 6 in.

The pillow-form shapes are sometimes arranged parallel to the bed, but are frequently inclined. They are often twice as long as thick, and average from one to two feet in length.

Externally the shapes of these masses recalled those of pillow-lavas, or the spheroidal weathering of dolerite, and since some of the pillows contained much felspathic material and some of the spheroids appeared to be due to weathering, their occurrence was sufficiently interesting to warrant further investigation, which showed that they were of two kinds.

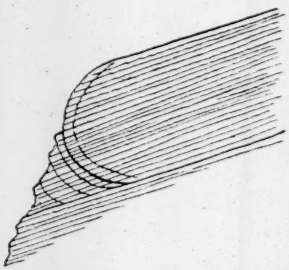

FIG. 2.—Shell-jointing in sandstone.

Two Types of Structure.

1. Structures due to jointing and weathering (shell-jointing).
2. Pillow-form or ball structures due to internal build.

1. Where the rocks are evenly bedded and well jointed the corners of roughly rectangular masses, blocked out by joints and planes of stratification, are liable to shell off in layers roughly concentric with the central portions of the blocks. As in dolerite the shell structure may be due primarily to shrinkage. In undoubted cases (Fig. 2) where this shelling off takes place [1] the fracture was unrelated to the lamination, which runs normally through the pillow. The exposed top corners of a block are usually shelled off first, unless the lower corners project prominently from the underlying beds. On hammering at such a pillow the concentric weathered shells may be knocked off in turn until only the tough unweathered core remains.

2. In other cases, if we hammer at a pillow or spheroidal mass we discover that its internal structure may correspond with its curved face; that is to say, the laminæ of sandstone are curved in conformity with the outer curve of the pillow. A good example occurs in an old quarry in Llwyn Bryn Dinas Wood, about one mile west of Llangedwyn. Some of the sandstone strata are evenly bedded and

[1] For this reason the rock is unsuitable for use in the exposed corners and angles of buildings. It is known locally as 'grinsel'.

apparently quite undisturbed, whilst others (Fig. 3) have ball structures strongly developed and exposed chiefly, be it noted, on their under surfaces. Where these surfaces curve upwards until they are nearly, or more than, at right angles to the normal plane of stratification, the sandstone laminæ curve upwards and over, in conformity with them. In one or two places shales are plastered against the curved surfaces as if squeezed into spaces between the spheroids.

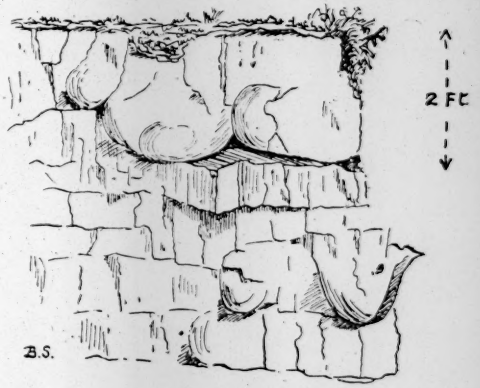

FIG. 3.—Ball structures in sandstone, Llwyn Bryn Dinas Wood, Llangedwyn.

This example seemed to furnish conclusive evidence in favour of the balls or spheroids being due to internal concentric lamination, yet the next time I came across semi-spheroidal masses their curved surfaces

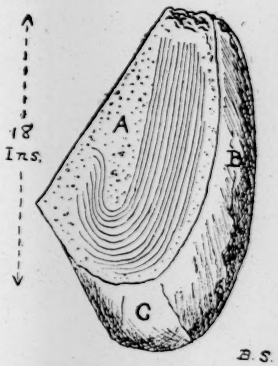

FIG. 4.—Sandstone 'ball', Tyddyn-main, Llansilin.

were due, quite as conclusively, to jointing and weathering. However, many cases of the real thing were quickly forthcoming, and I have since found that true ball structures are quite as common as, if not more common than, the rounded masses due to shelling.

Other examples occurred (i) in a quarry between the road and river east of Coed Fron-fraith; (ii) in a quarry about 200 yards west of Tyddyn-main; (iii) in a quarry at Tyn-y-ffridd in ashy sandstone, where shales are pinched in between two balls; (iv) on Moel y Gwelltyn, where the balls are from 18 inches to 2 feet in thickness; (v) in the crags west of, and overlooking, Moelfre (Fig. 1); (vi) in a quarry south of Pant-er-eos-uchaf; (vii) in numerous quarries and crags between Moelfre Hall and Moeliwrch on Gyrn Moelfre.

In some cases it is possible to study sections of the ball structures on joint faces where the lamination has been rendered visible by weathering. In a quarry about 200 yards west of Tyddyn-main (ii above, Fig. 4) a flat broken surface of a ball, in a big lenticle of sandstone, reveals its internal structure, for the exposed laminæ are curved back upon themselves in a sharp fold, to which the outer curve of the ball conforms.

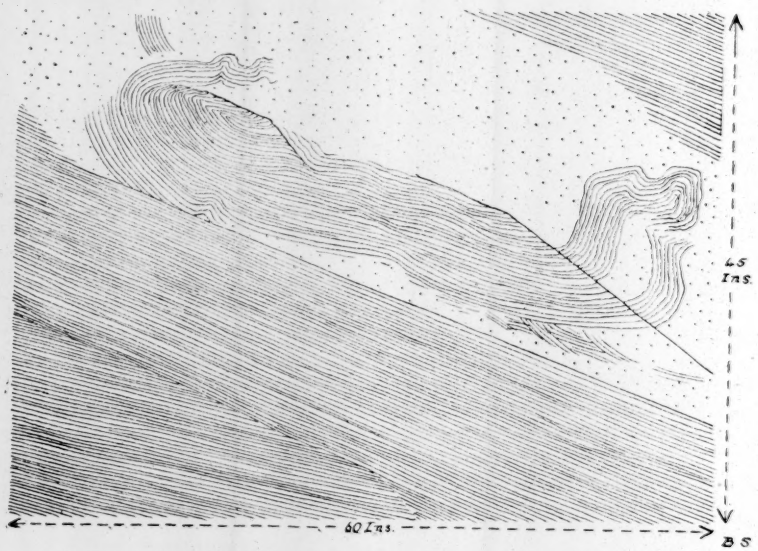

FIG. 5.—Contorted layers in sandstone near Pentre, Llansilin.

A better section is visible in an old quarry in a wood 200 yards east of Pentre, on a nearly vertical joint face which runs approximately in the direction of the dip (Fig. 5). It shows a well-laminated and slightly drift-bedded sandstone, in which some of the laminæ (about 12–15 to the inch) are strongly contorted, folded back upon themselves, and cut off from other parts of the rock by faults. The rounded ends of these curved masses are often buried in apparently structureless sandstone, whilst the disturbed horizon is both underlain and overlain by normally bedded sandstone. At some future date the balls will be developed by differential weathering of the structureless parts of the rock.

Cause of Contortion.

Anything more unlike concretionary action could hardly be imagined. To what, then, must these structures be attributed?

I can imagine no means that would avail to turn over, and break up, layers of sediment on this scale—sandwiched between normally bedded *identical layers of identically similar sandstone*[1]—after the higher layers had been deposited. Movements during consolidation, due to differences in composition, cannot be invoked, because there is no difference in composition. Nor can we appeal to cleavage-stresses, although in some cases, discussed below, they may have achieved something of a secondary order.

There remains to find some means whereby the sediment could have been disturbed before the higher undisturbed layers were deposited. Two agencies are possible: either (1) packing or sliding movements on gentle slopes owing to irregularity of deposition and gravitational creep, or (2) movements of overlying bodies of water as tidal or ocean currents.

Nature of the Movements.

The highly lenticular character of these beds has already been emphasized, and the examples figured show how the rock was drift-bedded and ripple-marked during deposition. Nothing is more obvious than that the sediment was transported by currents and laid down sporadically in fairly shallow water, layers of mud being frequently interspersed between layers of sand and silt. From these facts we may safely infer that the sea-bed was gently undulating. Again, the sediments were apparently formed off the shores of volcanic islands drained by rivers carrying ashy and other sediment to the sea, which would be agitated periodically by strong tidal currents. The large volcanic bombs and lumps of shale in the Bala ashes would seem to prove that the volcanoes rose above the water, for the bombs could not have been cast far from the vents had the latter been submarine.

Most of the sediment had apparently reached a state of pasty semi-consolidation that allowed of overfolding and thrusting within its mass, but its upper layers were still so incoherent that they could be stirred up and easily rendered structureless.

A lenticle of sandstone, deposited on a gentle slope, might find itself in a state of unstable equilibrium through gravitation alone, which would set up a tendency to creep and internal readjustment. Furthermore, the edges of a lenticle deposited on a slope of mud would tend to break up and have its detached fragments incorporated in the enveloping mud.

It is well-known how Glacial and post-Glacial gravels, resting on gentle inclines, have become contorted by gravitational creep. A mass of laminated sandstone under water would be an even more likely subject for this operation, which might be started or accentuated by tidal movements, or the sweep of changeable ocean currents.

[1] Contrast 'mud-lumps', where mud is squeezed out from between sandstones that are of different composition and grade of material (see later, p. 155).

Current Action.

The disturbing effects of current-action can indeed be demonstrated; for semi-rounded lumps of sandstone (1–2 inches across, in Llwyn Bryn Dinas Wood) occur in the shales lying between the thicker lenticles of sandstone, as if thin layers had been deposited and subsequently broken up, rolled along, and embedded in the mud. Conversely, the thicker sandstones contain little strips, angular pellets, or rounded pebbles of mudstone—proving without doubt that the beds were frequently torn up when they had barely attained a state of consolidation.

We may compare such destructive current-action with that to which I ascribe the contortions in the dolomitic sandstones in the Keuper Marl of Nottinghamshire.[1] In this connexion also, the occurrence of structureless sandstone in which the balls or pillows are embedded is suggestive.

Thus, although I am not an advocate of the efficacy of current-action to form the large ball structures met with in these Palæozoic sandstones, but prefer to think they are chiefly due to gravitational creep in lenticular beds, I am of the opinion that currents have played a greater part in aiding such movements than some geologists might admit.

Effects of Cleavage.

The effects of cleavage may now be considered. During the process of shearing and compression that induced cleavage the irregular lenticles of sandstone acted as resistant cores or sheets, and only yielded to the impressed forces after a struggle. In some cases they slid bodily through the shales, which were caused to flow round them like so much butter; in other cases they were bent and folded; whilst in others, again, they were faulted or broken into small masses—like the quartz veins in the Ilfracombe slates. The latter condition is so common that it is inadvisable to rely upon a dip taken in any small isolated mass of banded sandstone, for I have frequently found the true dip of the enclosing shales to be almost at right angles to that of the broken lenticle.

When the sandstones occur as large lenticles or clusters, the boundaries of the mass, or group, are often faulted, and the combination buckled into folds—structures which may be further complicated by post-cleavage movements. The shaly portions of the combination are frequently cleaved, whilst at other times the sandstones are cleaved as well. In the latter case the angle of cleavage in the sandstones is invariably higher than it is in the shales: an effect that would seem to imply that the thickness of the shale-belts, relative to that of the sandstones, has been decreased by cleavage-shear, and that the higher beds of sandstone have moved further than those below.

In the heart of a thick mass of sandstone cleavage has had little or no effect upon the relations of the ball structures to their surroundings; but where they occur at the margin of a lenticle (a very likely position) and where lumps of sandstone in the first instance have been detached

[1] "The Upper Keuper Sandstones of East Nottinghamshire": GEOL. MAG., 1910, pp. 302–11.

and isolated in the shales, the effect of the cleavage has been to jam these lenticle-noses or semi-rounded balls into the shales, which were thereby slickensided and plastered tightly upon them. In some cases, indeed, a sort of subsidiary cleavage (due to jamming) curves round the balls in places where the ordinary cleavage had little effect.

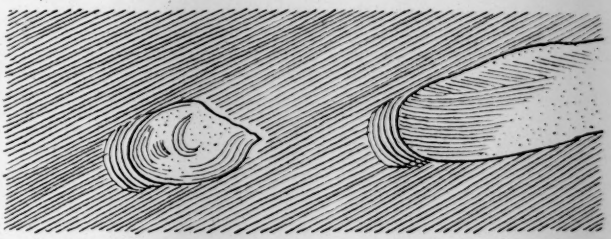

FIG. 6.—Diagram showing curved cleavage.

A local curved cleavage, developed in this definite manner, may either accentuate the true ball structures, or suggest ball structures even when the sandstone laminæ do not conform to the curved surface. Fig. 6 is an attempt to express these two cases diagrammatically.

Similar effects are liable to occur also on a large scale about masses of sandstone and shale 100–200 feet in thickness, the slickensides being represented by faults. In the lee of the mass we may find (taking the analogy from a 'rain-shadow') a 'cleavage-shadow', or locality in which the cleavage is modified or absent owing to the protection afforded by the sandstone.

Some allied phenomena.

Amongst allied phenomena we might instance the contortions and uneven deposition of some of the Wenlock–Ludlow beds of Denbighshire. These consist chiefly of blue shales with sandy laminæ which become clustered at frequent intervals to form sandy shales or thin beds of sandstone. The clusters are usually only half an inch or so in thickness, but some of the sandy beds may attain a maximum of 6–8 inches. Occasionally the sandy beds are split up by muddy

FIG. 7.—Folded layers of sandstone and shale, Pant-yr-onn, Llanelidan.

layers. In one case, near Pant-yr-onn, Llanelidan, an 8 in. band of laminated sandstone contained 6–7 muddy layers, those near the centre of the bed being thrown into gentle undulations, of wavelength about 9 inches and amplitude about 3 inches, whilst the upper and lower layers pursue a straight course (Fig. 7). Here and there the folded bands of mudstone thicken quite suddenly, especially on

the crests of the small anticlines. Had the folding been due to packing caused by cleavage-stresses the whole bed would have folded, instead of only the middle portion. The most likely explanation to account for the facts is that the composite bed was deposited on a slight slope, and a creeping movement was set up, whilst the layers were still soft, causing the bed to become undulose internally, and to thicken at the same time. The top and bottom of the bed would remain relatively undisturbed, but each individual layer of sandstone, between the little layers of mud in the middle of the group, would move slightly in the direction of the creep.

Signs of current-action and uneven deposition are common in these beds. In the quarry south-south-west of Nant Gaer, near Bryn Eglwys, there is a 6 in. band of slightly calcareous and fossiliferous laminated sandstone with uneven upper and lower surfaces. The upper has flowing curves which correspond roughly with the surfaces of the ripple-marks, whilst the lower is much more irregular, for the sandstone fills up little pockets that either have been torn out of the mud by current-action, or have been formed by the lowest sandstone laminæ buckling downwards whilst in a pasty state. The higher rippled laminæ of sandstone truncate this lower pocket-filling set (Fig. 8).

FIG. 8.—Sandstone in shale, Nant Gaer, near Bryn, Eglwys.

Most of this effect, as in the case of the Keuper 'skerries' of Nottinghamshire, I should attribute to current-action,[1] for the wave-length and amplitude of the ripples agree very closely with those proper for sandstones of this type, as worked out by Sorby.[2] The occurrence is altogether different from that shown in Fig. 7.

Conclusion.

Ball or pillow-form structures in sandstones, and certain bucklings and foldings, seem to be most satisfactorily explained on the assumption that they are primarily due to internal readjustments of freshly and unevenly deposited sediments, acting mainly under gravitation. These readjustments may be aided, or started, by the action of strong currents.

The above-mentioned structures and their attendant phenomena are not confined to Palæozoic sandstones,[3] but must occur frequently in

[1] "The Upper Keuper Sandstones of East Nottinghamshire": GEOL. MAG., 1910, pp. 306–7.

[2] "On the application of Quantitative Methods to the Study of Rocks": Q.J.G.S., vol. lxiv, pp. 171–233, 1908.

[3] I have recently seen ball structures in the sandstone of St. Bees Head, Cumberland, and Dr. R. L. Sherlock tells me that pillow-form masses of Magnesian Limestone overlie puckered Marl Slate in a cutting at the north end of Annesley Tunnel in Nottinghamshire.

the Mesozoic and Tertiary rocks, especially the latter. I am not aware, however, that much attention has been paid to them, although I am convinced that a strict examination of ripple-marks, current- and drift-bedding, internal creeping-movements, and removal of sediment by current-action would yield important results if studied in conjunction with present-day sedimentation in, and beyond, the mouth of one of our great tidal estuaries.

We want to know, for example, the extreme depth at which ripple-marks can be formed, and to what extent depth is a deciding factor. We require reliable data as to the rate at which sandy sediment may be accumulated and again removed by current-action; the relative effects of a flood- and ebb-tide on sedimentation; and if a layer of drift- or current-bedded sand is laid down by the one, how far it may be wiped out by the other, or covered up by further sediment. When we find the laminæ of false-bedding or ripple-drift (in a rock exposure) dipping in a certain direction, are we to assume that the sediment was carried directly to that spot from the land? These and similar questions may be difficult to solve, but would give scope to an investigator provided with a suitable boat, and ample leisure for the task.

The Mississippi Delta.

Since writing the above it has been my good fortune to light upon an instructive paper dealing with the conditions obtaining in the region of the Mississippi Delta.[1] Investigations were undertaken with the object of discovering the nature and mode of formation of the mud-lumps that obstruct the navigation at the river mouths. The results achieved, although they have not fully settled the origin of the mud-lumps, are enlightening.

It has been shown, for example, that the deposits near the mouth of the river consist of lenticular layers of dark-blue clay, fine sand, and silt, and a great many beds of intermediate character, each of which grades into the adjacent beds. The sandy beds, and those of mixed sand and clay, are much more rigid than nearly pure clay. The most rigid material is a mixture of sand and clay in certain definite proportions, whilst some of the clays are very fluid. The resemblance between these deposits and some of those of Ordovician and Silurian age, as they would have been at the time of their formation, is striking; although this, of course, does not imply that the Lower Palæozoic deposits were of deltaic origin.

Just off-shore, and adjacent to the mouths of the river, silt is accumulating at the rate of several inches a year, and the character of the deposit varies from season to season. During high-water—the first half of the year—the sediment is coarser than during the low-water period. The apparent result is a structure somewhat resembling the annual rings of growth of trees. This is a suggestive fact, if we bear in mind the sequence of sedimentation of some of the older rocks, in e.g. the Wenlock–Ludlow Series (see p. 153).

Again, certain features of the Delta suggest that it is affected by a process of bodily flowage towards the sea, giving rise to readjustment

[1] The mud-lumps at the mouths of the Mississippi, by E. W. Shaw, U.S.G.S., Professional Paper 85-B, 1913.

between the more or less resistant layers of sediment, both in the Delta itself and in the sea-bottom just off-shore.[1] The surface of the deltaic deposits is also subsiding, the subsidence being most rapid where the Delta is growing most rapidly; and the material is presumably becoming more compact and losing its very watery condition. These, again, are significant facts, and bear directly upon the subject of this communication. We have at once a clue to much that was pure surmise—the unstable relations of these sandy, silty, and clayey deposits to one another, and the comparative rigidity of some of the more sandy beds, which would allow of thrusting and buckling within them, although they were still in a pasty condition.

III.—The "Pietre Verdi" of the Piémontese Alps.

By C. S. Du Riche Preller, M.A., Ph.D., M.I.E.E., F.G.S., F.R.S.E.

IN a previous paper on the Permian Formation in the Alps of Piémont, Dauphiné, and Savoy,[2] I referred incidentally to the large masses of pietre verdi or greenstones which constitute perhaps the most striking geological feature of the extensive areas covered by the crystalline rocks of the Piémontese Alps in a crescent-shaped curve about 200 miles in length from the Maritime range to Monte Viso, Grand Paradiso, and Monte Rosa. In the present paper I propose to deal more fully, although necessarily within narrow limits, with these pietre verdi which, owing alike to their extraordinary development, variety, and complexity, to their intimate association with each other and with the crystalline sedimentary rocks, and to their intricate composition and origin, have for the last fifty years presented most interesting problems and passed through many remarkable phases of interpretation. As a necessary preliminary to a description of the different areas, it will be convenient to briefly consider the most recent classification of the crystalline formations of the Piémontese Alps generally, and of the pietre verdi rocks in particular.

I. Classification of the Crystalline Formations.

In a short paragraph of the previous paper already quoted, I outlined the sequence of the crystalline rocks of the Piémontese Alps as evolved by Zaccagna in his revealing memoirs of 1887 and 1892.[3] In this classification he retained Gastaldi's two principal pre-Palæozoic zones or horizons,[4] but with this essential difference, that for Gastaldi's upper or so-called pietre verdi zone he substituted

[1] The mud in the 'lumps' is supposed to be squeezed out from between the sandy beds.

[2] Geol. Mag., January, 1916, p. 7; ibid., p. 15.

[3] D. Zaccagna, "Studi geol. sulle Alpi Occid.": Boll. R. Com. geol. d'It., 1887, p. 346 et seq. "Riassunto di Osserv. sul Versante Occid. Alpi Graje": ibid., 1892, p. 175 et seq.

[4] B. Gastaldi, "Studi geol. sulle Alpi Occid.": Mem. R. Com. geol. d'It., 1871, vol. i, p. 3 et seq. "Spaccato geol. lungo le valli sup. Po e Varaita": Boll. R. Com. geol., 1876, p. 104 et seq.

the mica-and-calc schist zone with pietre verdi as associated rocks, the latter being, in point of superficial area, a subordinate, the former the predominant part of the whole formation. Zaccagna's two Archæan zones thus comprised: (1) a lower one, restricted exclusively to primitive gneiss and granite without pietre verdi; and (2) an upper one, graduating, in ascending order, from minute and tabular gneiss to mica-schists and calc-schists, each group with crystalline limestone and pietre verdi. This classification, in its logical sequence and convincing simplicity, received the imprimatur of the Italian Geological Survey under its eminent Director, the late Comm. F. Giordano,[1] and was also accepted by the French Survey, by Bertrand, Termier, and other French geologists. It derived additional force from the more intense metamorphism and crystallinity, progressing from west to east, of the rocks on the Piémontese as compared with those on the French side of the Western Alps; and this, together with the fact that until then, about 1890, no determinable fossils had been found even in the uppermost calc-schist horizon, warranted the entire crystalline series of Piémont being classed as of pre-Carboniferous, and, in the absence of the lower Palæozoic, of Archæan age.

But in 1894 Bertrand returned to his former view of the Mesozoic age of the schistes lustrés which, in opposition to the late Professor Lory's Triassic and to Zaccagna's Archæan views, he and Termier had already pronounced Liassic in the well-known case of Mont Jovet in Tarantaise (Isère Valley).[2] In his *Études dans les Alpes Françaises*[3] Bertrand maintained the Liassic age of the calc-schists not only on the French but also on the Italian side, on the ground that lower Triassic masses frequently underlie the calc-schists. Even before the publication of that work, Professor Parona, of Turin, had discovered Radiolaria in the silico-calcareous mass associated with the calc-schists and pietre verdi (serpentine) of Mont Cruzeau, near Cesana,[4] a discovery followed a few years later by other evidence of characteristic Liassic, Rhætian, and Triassic fossils in the dolomitic and calcareous masses which, in the lower as well as in the upper valleys of both Southern and Northern Piémont, occur at varying levels of the calc-schist horizon, either resting on, or intercalated between, or in some cases at the base of, the crystalline calc-schist strata. These discoveries were due chiefly to the untiring industry and perseverance of Franchi, who, in two important memoirs of 1898 and 1904,[5] claimed to have established the Mesozoic,

[1] Boll. R. Com. geol., 1887, pp. 342–5.

[2] P. Termier, "Sur le Permien du massif de la Vanoise": Bull. Soc. géol. France, vol. xxi, p. 124 et seq., 1893.

[3] M. Bertrand, Bull. Soc. géol. France, vol. xxii, p. 69 et seq., 1894.

[4] C. F. Parona, "Sugli Scisti silicei a radiolarie di Cesana presso il Monginevra": Atti R. Acc. Sc. Torino, vol. xxvii, 17. Gennajo, 1892; also noticed in Davies & Gregory's paper on "The Geology of Mont Chaberton", Q.J.G.S., 1894, p. 303 et seq.

[5] S. Franchi, "Sull' età mesozoica della zona delle pietre verdi nelle Alpi Occidentali": Boll. R. Com. geol., 1898, pp. 173, 325 et seq. "Ancora sull'età mesozoica, etc.": ibid., p. 125 et seq. Franchi, Novarese, and Stella were in charge of the detailed survey of the Piémontese Alps for the new 1:100,000 map in

and more especially the predominantly Liassic, age of the calc-schist formation, including in the same the pietre verdi as associated rocks. He thus assimilated the age of that formation and that of the schistes lustrés in accordance with Bertrand's views, with which he is thoroughly imbued and which, since Bertrand's death, have been upheld and even carried considerably further by Termier.

Franchi's memoirs and his evolution from the Archæan to the Mesozoic led to a controversy as interesting as it was vigorous and protracted, between Zaccagna and himself, not as to the facts, which were not in dispute, but as to the interpretation of the same. To Franchi's contention Zaccagna[1] opposed, on stratigraphical grounds, his own explanation that the fossiliferous calcareous and dolomitic deposits occur in eroded gaps and as squeezed wedges (*pizzicature*) in the crystalline calc-schists, in which they were infolded by dynamic action, in certain cases by displacements due to local overthrusts, and that as such they are quite distinct from the true calc-schists, whose pre-Palæozoic age he therefore strenuously reaffirmed.[2] In the result Professor Taramelli, of Pavia, and Professor Parona, of Turin, as referees appointed by the Geological Survey, recommended, in their reasoned report of 1911,[3] that for the purposes of the new large-scale map 1 : 100,000 of the Piémontese Alps, Franchi's interpretation, as being, in their view, more convincing and up-to-date, should be adopted, but with the explicit and judicious reservation that the question cannot be considered settled but remains open ; that at a lower horizon there may be calc-schists

conjunction with Mattirolo, who supported Zaccagna's interpretation. Franchi published in Boll. R. Com. geol., 1909, p. 252, a forty-page reference of the literature on the crystalline schists from Gastaldi (1871) downwards.

The principal localities which yielded Triassic and Liassic fossils in the calcareous and dolomitic masses of the calc-schist horizon are the Grana, Narbone, Maira, Elva, and Varaita Valleys in Southern Piémont ; Chianoc in the lower, and Rocca d'Ambin, Gad d'Oulx, and Bardonecchia in the upper Susa Valley ; Villeneuve in the upper Aosta Valley, and the Col du Petit St. Bernard, all in Northern Piémont. The fossils, most of which were determined by Professor Di Stefano and Professor Canavari, include, among others, Radiolaria, Belemnites, *Arietites*, Crinoids, *Encrinus*, *Pleurotomaria*, *Avicula*, *Corallari*, *Gyropellæ*, *Pentacrinus*, *Phylloceras*, etc.

[1] D. Zaccagna, "Osservazioni sugli ultimi lavori intorno alle Alpi Occidentali" : Boll. Com. geol., 1901, pp. 4, 129 ; 1902, p. 149 ; 1903, p. 297.

[2] Zaccagna's interpretation agrees with Professor Bonney's view that nothing is more common in the Alps than Jurassic and Triassic wedges in the crystalline schists. "Mesozoic Rocks and Crystalline Schists in the Lepontine Alps" : Q.J.G.S., 1894, p. 285 ; also ibid., p. 277. Baretti (*Studi Gran Paradiso*, etc., 1876–7) also considered the French calc-schists the upper and the Piémontese calc-schists as the lower crystalline formation.

[3] T. Taramelli and C. F. Parona, "Relazione sull'età da assegnarsi alla zona delle pietre verdi nella Carta geol. delle Alpi Occidentali" : Boll. R. Com. geol., 1911, pp. x–xxiv. The controversy between Franchi and Zaccagna turned more especially on the great calc-schist area extending from the Gesso Valley in Southern Piémont parallel to the Franco-Italian frontier to the Susa and Aosta Valleys towards Monte Rosa. The smaller, isolated area of Courmayeur, running parallel to Mont Blanc, was recognized as Liassic and Triassic, and was, therefore, not in dispute.

in Zaccagna's sense; and that the Piémontese Alps, in their elusive complexity, may yet reveal the most surprising phenomena just when the problem of the crystalline schists and pietre verdi appears to have been solved.

Thus, in the most recent Italian Geological Survey map 1 : 100,000, as also in the one of 1 : 400,000 of 1904, the Piémontese calc-schist formation has been rejuvenated as equivalent to and contemporaneous with the schistes lustrés of the French, the Bündnerschiefer of the Swiss, and the Schieferhülle of the Austrian Alps. It figures, therefore, as the Liassic–Triassic crystalline "Piémontese" facies, with two subordinate facies—the "mixed" and the "ordinary" Trias. This rejuvenation, which is practically a reversion, *mutatis mutandis*, to Sismonda's "metamorphosed Jurassic schists" of the early 'sixties, entailed a similar stratigraphical process as regards the mica-schists and the minute, tabular, and graphitic gneisses which, accordingly, are now assigned to the Permo-Carboniferous, corresponding to Bertrand's and Termier's "série cristallophylienne permo-carbonifère". The only formation left to the Pre-Carboniferous (or Pre-Palæozoic) is therefore that of the primitive gneiss belt of the Mercantour, Maira-Dora, and Gran Paradiso massifs, which formation constitutes the practically undisturbed substratum of all the more recent series.[1]

This primitive gneiss, often of granitoid and porphyroid structure with large felspar crystals up to 8 centimetres in length, differs lithologically from the more recent minute and tabular gneiss, chiefly in that the small-grained elements of the latter are conspicuously rich in quartz and predominantly white mica. As regards the calc-schists, they are composed prevalently of calcite, aggregations of quartz in minute granules, and with white or greenish mica, the rock being generally of grey and often blackish colour due to a carbonaceous pigment, with numerous minute crystals of pyrite and other metallic minerals. When this typical calc-schist is deficient in calcite or loses it altogether, it assumes an essentially phyllitic character; when, on the other hand, calcite predominates over the other minerals, the calc-schist becomes micaceous crystalline limestone or 'calcefiro'; and when the crystalline limestone is, by contact, impregnated with serpentinous matter, it becomes 'ophicalce', as e.g. the green marble of Susa.

[1] The official geological map of France, 1 : 1,000,000, published in 1904, which extends to the Italian side as far as the Po Valley, includes in the Permo-Carboniferous not only the minute and tabular gneiss and mica-schists, but also the primitive gneiss belt, for which there is no warrant. Similarly, Termier ("Les schistes cristallins des Alpes occidentales," Comptes Rendus du Congrès géol. Vienne, 1913) embraces in his *série cristallo-phylienne triassique compréhensive* all the younger formations down to the Eocene inclusive. Both cases are ultra-synthetic, and are not accepted by the Italian Survey.

Professor Gregory's view that the gneisses which he terms *Waldensian* (Q.J.G.S., 1894, p. 232 et seq.) are Pliocene and intrusive runs counter to the accepted interpretation of the coarse-grained gneiss being the primitive, viz. 'fundamental', substratum of the Cottian and Grajan Alps. Professor Gregory's conclusions are traversed also by Novarese, "Rilevamento geol. Valle Germanesca (Alpi Cozie), 1894," Boll. R. Com. geol., 1895, p. 277 et seq., and Franchi, ibid., 1897, p. 13 et seq.

The new classification, besides harmonizing with the most recent interpretations west and north of the Alps, has the signal advantage of having eliminated Gastaldi's "pietre verdi zone", which, in his separate and far too comprehensive sense, had become a fruitful source of misconception. As experience has shown, pietre verdi are not peculiar to any particular horizon, and throughout Italy, as elsewhere, occur in all the formations from the Eocene down to the Palæozoic; in the Piémontese Alps, though in a special form, even in the primitive gneiss.

II. Classification of the Pietre Verdi.

In order to avoid tedious repetition, it will be convenient to specify briefly the leading varieties of the pietre verdi, some of which have characteristics peculiar to the Piémontese Alps. Gastaldi, with his wonderful intuition and perspicacity, laid down certain broad lithological distinctions which, in the main, are still correct. They were used by his immediate contemporary followers Strüver and Baretti, and after them by Bucca,[1] in their excellent and diffuse macroscopic and microscopic investigations, and until recently also by Zaccagna and Mattirolo; but the results of the detailed survey and the consequent extension of microscopic work, notably by Franchi, Novarese, and Stella, have led to revised and more precise definitions, more especially in reference to the amphibolic and prasinitic series which Gastaldi included indiscriminately in his 'amphibolic' or 'magnesian schist zone'.

On the rational ground that not amphibole, i.e. hornblende, but triclinic felspar is the most prevalent constituent of pietre verdi, the revised nomenclature divides all the basic rocks of the Piémontese Alps into three groups on a felspathic basis, viz. rocks in which felspar, as a constituent element, is essential, subordinate, or absent. In the following table I have enumerated only the principal, most diffused rocks, without their schists, their infinite graduations, and their often overlapping varieties and combinations.[2]

Pietre Verdi Rocks.

I. *Rocks with primitive elements.*

Felspar	(1)	*Essential.*	Diorite, diabase, porphyrite, gabbro, and their varieties.
	(2)	*Subordinate.*	Felspathic lherzolite, felspathic hornblendite.
	(3)	*Absent.*	Lherzolite and peridotite, hornblendite.

[1] G. Strüver, "Cenni sui graniti massicci delle Alpi Piémontesi e sui minerali delle valli di Lanzo": Mem. descr. Carta geol. d'Italia, 1871, p. 37 et seq. M. Baretti, "Studi geol. sul gruppo del Gran Paradiso": Mem. Acc. Lincei Torino, vol. i, p. 197 et seq., 1876–7. L. Bucca, "Appunti petrogr. sul gruppo del Gran Paradiso": Boll. R. Com. geol., 1886, p. 449 et seq.

[2] The table is founded on the nomenclature worked out by Novarese and Franchi, Boll. R. Com. geol., 1895, p. 164 et seq. and p. 181 et seq.; but I have arranged it somewhat differently so as to group the rocks with primitive and those with secondary elements separately and more prominently.

II. *Rocks with secondary elements.*

FELSPAR
- (1) *Essential.*
  - (*a*) Prasinite group: with a dominant non-felspathic element, viz. chloritic, amphibolic (actinolite and glaucophane), or epidotic prasinite, and varieties.
  - (*b*) Euphodite and its varieties.
- (2) *Subordinate.*
  - (*a*) Amphibolite group: felspathic and epidotic amphibolite with frequent glaucophane.
  - (*b*) Epidotites and zoisitites, felspathic.
- (3) *Absent.*
  - (*a*) Amphibolite group: epidotic and garnetiferous amphibolite with dominant glaucophane, eclogite.
  - (*b*) Epidotite, zoisitite.
  - (*c*) Serpentine, serpentinous, chloritic, and talcose schist.

It will be seen that the old generic group of amphibolites or hornblendic rocks is separated into amphibolites proper and prasinites, the last-named designation having been adopted from Kalkowsky and Zirkel as basic rocks or 'Grüneschiefer' of a felspathic basis with chlorite, hornblende (the bright-green actinolite or the bluish-green or violet fibrous glaucophane) and epidote, one of these being dominant as a non-felspathic element. The amphibolites, largely derived from diorite and composed of albite, epidote, and dominant amphibole, are mostly compact, passing to schistose, although the hardest, massive amphibolite, viz. 'hornblendite' or 'Hornblendefels', is, in large masses, comparatively rare in the Piémontese Alps. The prasinites, on the other hand, are on the whole less compact and more often schistose, and in the main, like the amphibolites, altered, transformed, or metamorphosed from massive eruptive rocks. They often contain, as an accessory mineral, white mica, but rarely biotite, and include, as a largely diffused variety, the chloritic rock 'ovardite', first recognized and so named by Strüver[1] from Torre d'Ovarda, a ridge in one of the three Stura di Lanzo valleys. It is composed of epidote, microscopic amphibole, and predominant chlorite in a plagioclase groundmass. Amphibolic schist, the equivalent of 'Hornblendeschiefer', is intermediate between amphibolites proper and prasinites.[2]

A further distinction made is that between gabbro and euphodite in the sense that gabbro is restricted to the primary eruptive rock with its elements unaltered, while in euphodite the triclinic felspar is already altered to saussurite and the diallage to smaragdite—the latter being, like epidote and the amphibole varieties, a largely diffused mineral in the Piémontese Alps.

Again, massive serpentine, as the direct product of altered lherzolite and peridotite, is distinct serpentine schist, which is a further

[1] Strüver, *Una Salita alle Torre d'Ovarda*, Torino, 1873, and Bucca, loc. cit., 1886, p. 453.

[2] The felspar-actinolitic rock noticed by Professor Bonney near Fenestrelle in the Chisone Valley ("Two Traverses of the Crystalline Rocks of the Alps": Q.J.G.S., 1889, p. 80 et seq.) is an amphibolic prasinite, viz. ovardite, while the schist with glaucophane, the epidiorite, and the dark-green porphyrite mentioned by Professor Gregory in his "Waldensian Gneisses", loc. cit., come under the category of prasinites (ovardites) and amphibolites.

stage of alteration, and still more from serpentinous schist, which, occurring frequently as intermediate between crystalline schists or, again, between crystalline limestone and pietre verdi, is the product of chloritic decomposition of the latter. As such it may, by the abstraction of magnesia, be derived from any of the basic rocks with altered elements, notably from euphodite, amphibolite, and prasinite, or their schists, although the prototypes of these rocks—gabbro, diorite, and diabase—have, apparently, no identity of origin or affinity with serpentine proper. So-called serpentinous schist is therefore *pseudo*-serpentine, and represents, together with chloritic and talcose schist, probably the last stage of alteration and metamorphism, not only of serpentine but of some of the other pietre verdi series.

The rocks with altered elements often assume a laminated, gneissiform structure, and exhibit a marked affinity with gneiss or, again, with mica-schists and even with calc-schists. Thus minute gneiss becomes amphibolic, prasinitic, or epidotic; mica-schist becomes epidotic and even more frequently glaucophanic when in association with the blue glaucophane or gastaldite variety; while ovardite, when very rich in chlorite and taking up mica, quartz, and calcite, passes into prasinitic calc-schist and phyllite.

The massive eruptive rocks with primitive elements—diorite, diabase, gabbro, pyroxenic-biotitic porphyrite (Gastaldi's melaphyre), and the enormous peridotitic masses—occur more especially in the gneiss and mica-schist area of Northern Piémont, that is, in the so-called dioritic belt or 'Ivrea zone' which extends from the eastern spurs of the valleys converging near Avigliana, west of Turin, to the Lanzo spurs, and thence north-east to Ivrea, Biella, and the Sesia valley, and beyond the latter to the Strona valley near Lake Orta. The same 'Ivrea zone' also extends into the Aosta valley and the valleys descending from Monte Rosa. The amphibolic, prasinitic, euphoditic, and serpentinous series with secondary elements, on the other hand, predominate in the calc-schist and mica-schist area from the upper Lanzo valleys south to Monte Viso and the Maritime Alps, and extend into the Permian and Triassic formations of the latter. The considerable euphoditic and diabasic masses of the Grana and Maira valleys south of Monte Viso are all more or less profoundly metamorphosed to epidotic (zoisitic), amphibolic, and prasinitic rocks,[1] and therefore do not belong to the category of eruptive rocks with primitive elements.

The constant and intimate association of the pietre verdi not only with each other but with the stratified mica- and calc-schists led Gastaldi, as previously stated, to regard all those rocks, with the only exception of the primary eruptive rocks of the Ivrea belt, indiscriminately as metamorphosed sedimentary.[2] The pietre verdi are now generally recognized to be in the main derived from eruptive rocks and some probably from tuffs or muds. At the same time the constant alternations, amounting to interstratification, of the

[1] S. Franchi, "Alcune metamorfosi di eufotidi e diabasi Alpi Occid.": Boll. R. Com. geol., 1895, p. 181 et seq.

[2] Hence his well-known dictum: "In the Piémontese Alps plutonism is a myth."

pietre verdi with each other; their stratiform, if not actually stratified, character in relation to the sedimentary rocks, and their frequent wedges and lenticular intercalations in the latter—all these phenomena on a large scale still present an intricate problem to which I shall refer in the descriptive sequel of the present paper.[1] The problem of the age of the pietre verdi in relation to the older rocks is, of course, rendered more difficult by the obliteration in the latter of organic remains through the ceaseless action of metamorphism past and present, or, in the words of Gastaldi: "while Nature gives us on this Earth myriads of living species, she with relentless hand destroys all trace of former life below."

(*To be concluded in our next number.*)

IV.—The Application of Petrological and Quantitative Methods to Stratigraphy.

By P. G. H. Boswell, A.R.C.Sc., D.I.C., F.G.S., Imperial College, London, S.W.

(*Concluded from March Number, p. 111.*)

ALTHOUGH detrital mineral work is as yet in its infancy, sufficient has been accomplished to show that we may look to it with success for indications of changes of drainage direction, evidences of denudation by reversal of the order of respective mineral assemblages from a sequence of rocks,[2] and generally for information regarding details of palæogeography. Professor A. de Lapparent referred to Professor L. Cayeux's work as proving the proximity of land, composed of primary rocks, to Lille in Landénian times.[3] Dr. H. H. Thomas was able to demonstrate the change in source, and therefore in direction of drainage, of the river-borne heavy minerals in the Bunter sandstones of South Devon,[4] the occurrence of garnets and staurolite being especially significant. Dr. T. O. Bosworth, in some preliminary work upon the detrital minerals of the Carboniferous Sandstone of the Midland Valley of Scotland, was led to the conclusion, partly by the respective presence and absence of garnets, that the beds could be divided into a series of great lenticular masses of sediment introduced from directions varying from north and north-west to north-east, east, and south.[5] Mr. W. R. Smellie has discussed in rather more detail the origin of the minerals in the Upper Red Barren Measures of the Glasgow Basin, the drainage having been from the west or north-west.[6] As a result of the study of the Tertiary sediments of East Anglia, the writer has been able to prove that the

[1] Professor Bonney has described an instructive case of conversion of greenstone into schist on a small scale in the Bernina region, Q.J.G.S., 1894, p. 279 et seq.

[2] This idea was suggested for contained boulders by Professor Charles Lapworth in connexion with the Carboniferous conglomerates of Halesowen in Worcestershire.

[3] *Traité de Géologie*, 5th ed., vol. iii, p. 1492, 1906.

[4] Q.J.G.S., vol. lviii, p. 620 (Sand of Bunter Pebble-bed), 1902; vol. lxv, p. 229 (New Red Sandstone), 1909.

[5] Proc. Geol. Assoc., vol. xxiv, p. 57, 1913.

[6] Trans. Geol. Soc. Glasgow, vol. xiv, p. 271, 1912.

source of the Pliocene material was from the area of the Ardennes, etc., on the south-east, but that the minerals of the Eocene beds were derived from an entirely different direction, possibly from the west or south-west. The overlying Lower Glacial deposits were derived, as their boulders also indicate, from the north, and possibly the north-east and north-west. These are broad generalizations only, but the subject is susceptible to more exact treatment which would lead to a correspondingly closer realization of ancient changes in geography.

Unconformities are usually emphasized by the changes in mineral composition, and these support palæontological and field-evidence. Changes in the distribution of land and water and in the direction of the large rivers are thus revealed. As an outstanding example may be mentioned the contrast between the fine-grained residues, consisting largely of staurolite, kyanite, tourmaline, hornblende, and pyroxene, which are characteristic of the London Clay in Suffolk, and the coarse muscovite, red garnet, andalusite, staurolite, epidote, etc., of the overlying Boxstones at the base of the Crag of Rupelian, Miocene, or Diestian age.

Recent work has possibly had a tendency to lead geologists to expect too much in certain directions from the comparative study of the residues of sediments, and it should therefore be stated at once that it is improbable that mineral constitution will have any correlative value over wide areas, certainly not comparable with that of fossils. From the nature of the subject we should expect various portions of basins of deposition to derive their material from different directions and sources. The writer has, however, endeavoured to show recently that mineral constitution, when fossils are rare or lacking (and if present, of wide range), has a distinct stratigraphical value over limited areas, when abundant samples are collected from numerous localities and horizons.[1] For this purpose the mineral assemblages of all the divisions of each of the geological stages of a district must be known. In connexion with these statements it should be said that the mineral assemblage of the Lower Greensand over most of its outcrop very closely resembles that of the Reading Beds of South-East Suffolk and Northern Essex, which beds in turn are extremely similar in mineral composition to the Bagshot Beds of the area around Claygate and Oxshott in Surrey. Again, the mineral constitution of the various divisions of the Eocene beds in East and West Kent is much more similar throughout than in the corresponding divisions in East Anglia, where there is a greater variety of minerals. The respective Thanet Beds, Woolwich and Reading Beds, etc., in the two areas do not resemble each other in petrology, and no correlation could be attempted on such evidence alone. The composition of the Thanet Beds around Lille, as detailed by L. Cayeux,[2] is again different from either.

Nevertheless, there are broad groupings which hold over a considerable area. Although the members of the Eocene Series differ among themselves, and each member may vary in composition over

[1] Abstr. Proc. Geol. Soc., No. 973, p. 76, etc., 1915.
[2] Ann. Soc. Géol. Nord, vol. xix, p. 264, 1891; also p. 90.

a wide area, all the Eocene beds in the London Basin appear to conform more or less to a general type characterized by the occurrence of abundant kyanite, staurolite, tourmaline, zircon, and rutile, and less commonly, green hornblende and small colourless garnets. The various beds of the Pliocene Series from Cornwall to East Anglia and Belgium all possess more or less similar mineral assemblages, the chief members of which are red garnet, muscovite, andalusite, staurolite, epidote, etc. The distinction from the Eocene Series is very marked.

As a final example may be quoted the sands forming the lowest part of the Inferior Oolite, the mineral composition of which is very distinctive, and yet maintains practically the same character when the beds are traced from Yorkshire by way of Northampton, the Cotteswolds, Bath, and Yeovil to the Dorset coast.

While correlation of smaller geological divisions over considerable areas is fraught with difficulty, the mineral constitution of the different beds is of great stratigraphical value, as has been stated, over limited areas. It has been shown, for example, that the Thanet Beds, Reading Beds, and London Clay in East Anglia have each a characteristic mineral assemblage by which they may be recognized, provided that we know also the mineral composition of all the other Tertiary beds from the top of the Chalk to the post-Glacial and Recent.[1] Speaking generally, each mineral assemblage remains constant over an area of nearly 500 square miles, and appears to be independent of the lithological variations of the bed containing it.[2] That there is a limit to this constancy is shown by the fact that the Reading Beds, when traced as far to the south-west as Bishop's Stortford and Hertford, begin to show a variation in mineral character. The change in mineral composition of the Reading Beds with respect to the underlying Thanet Beds may be due in part to difference of mechanical composition, and therefore to difference in conditions of deposition, resulting in concentration of certain minerals and decomposition of others, but whatever may be the cause the variation observed has an important stratigraphical value. The green and brown hornblende, pyroxene, biotite, apatite, etc., of the Thanet Beds disappear, and it is not until we reach the London Clay that some of these minerals reappear. The large and characteristic grains of kyanite, staurolite, and tourmaline present in the Reading Beds have disappeared in the London Clay, but green hornblende becomes abundant, and muscovite and colourless garnets more common. The detrital material is of fine grain, and therefore provides the more contrast with the very coarse stuff found in the Boxstone Bed at the base of the Suffolk Crags.

[1] Abstr. Proc. Geol. Soc., No. 973, p. 76, 1915.

[2] Very recently (March, 1916), in a lecture before the Geologists' Association, my friend and colleague, Mr. V. C. Illing, has claimed that the horizons of the unfossiliferous and oil-bearing sediments of the south-western part of Trinidad may be identified and correlated over a limited area by means of their mineral assemblages. If this contention is supported by the evidence (and from an examination of the residues I believe it is), the hitherto purely academic study of the petrology of sediments becomes at one bound of great economic importance.

The composition of the different zones of the Coralline, Red, and Norwich Crags is similar to, but not of so rich a type as, that of the Boxstones. The Chillesford Beds (late Pliocene) are much enriched in muscovite. The Westleton Beds (? early Pleistocene) show, as compared with the Pliocene beds below and the glacial deposits above, rather an impoverished assemblage which may have been derived from the Chalk and Eocene beds with a slight admixture of Crag detritus (garnets, etc.). The purity of the Westleton pebble-beds (mainly flint and quartz) and freedom from foreign boulders is interesting in this connexion. The glacial deposits yield, as no doubt would be expected when the variety and extent of the rocks laid under contribution are considered, a very rich mineral suite, the abundance and variety of which are unparalleled by any other deposit, and only approached by the Pliocene. Abundant garnets, amphiboles, and pyroxenes (sodic varieties included), epidote, micas, apatite, staurolite, kyanite, tourmaline, etc., make the deposits easily recognizable under the microscope or high-power hand-lens (× 20). It is noteworthy that andalusite is not nearly so abundant as in the Crag or in the glacial deposits of the West of England. The post-glacial gravels, sands, and brickearths, and the river terrace sands, loams, and alluvium, contain similar mineral assemblages to the glacial beds, and are no doubt derived largely from them.

The value and limitations of the application of petrographic methods to stratigraphy are well illustrated by the consideration of a sequence of deposits in one area such as that just mentioned.

First we may consider the limitations (apart from those resulting from attempted wide correlation). The Upper and Lower Glacial beds of East Anglia differ much in field characters, in mechanical composition, and in their included boulders, indicating two different directions of advance for the ice which produced them. It is very difficult, however, to tell the Upper from the Lower beds by the heavy detrital mineral assemblage, notwithstanding the fact that their mechanical analyses conform to two very different types. This may be due to the mineral richness of each. Again, it was hoped that the various zones of the Red Crag, when traced northwards, might show, together with the increasingly boreal fauna, a corresponding change in mineral constitution (the basin was closed on the south and opened on the north in late Pliocene times). No such variation has been observed, and it seems probable that the drainage direction and rocks undergoing denudation to produce the Crag sands, etc., remained the same throughout Pliocene times.

On the other hand, the advantages of the method are great. It has now become possible to identify any East Anglian bed (allowing for the limitations just detailed) from its detrital mineral suite, and to say when the mineral assemblage of any particular bed is pure, or when it has been contaminated with an admixture of material from another bed. A few actual examples may be quoted. Considerable glacial disturbance of the East Anglian deposits has frequently taken place locally in Southern Suffolk, etc., and it is often desirable to know whether a limited exposure shows a bed in situ, undisturbed and uncontaminated. Should the bed have been redeposited in

Glacial times, even if its original characters are retained, its detrital minerals tell their tale. The pale sands of the Reading Beds, Crag, and Glacial beds often resemble one another closely, and it has hitherto been difficult or impossible to identify with certainty an included mass of such sands in a large glacial disturbance.[1] Examination of the mineral assemblage allows a determination to be made, for example, as to whether the sand is a pure Reading Sand or one contaminated by an admixture of glacial detritus.

The pebble-bed at the base of the London Clay (on the horizon of the Blackheath Beds of the South of England) has in places in East Anglia been rearranged upon the shores of the Crag sea. This is indicated at times by the iridescent ferruginous coating upon the pebbles and the admixture of teeth and coprolites in the bed, but in some cases, except for the presence of reddish sand, it is difficult to say whether the bed is of Eocene or Crag age (that is, rearranged in Red Crag times). An analysis of the sandy material of the bed is sufficient to settle the point, for the Pliocene minerals are distinctive and easily recognizable, while those of the normal Eocene pebble-bed conform to the suite of the Reading Beds.

In the area where overlap of the Thanet Beds by the Reading Beds takes place (in South-West Suffolk and North-West Essex), the latter assume the lithological characters of the former and rest directly on the Chalk. They contain a 'bull-head' flint-bed, and are glauconitic clayey sands. When isolated sections in Drift-covered outliers occur on the north-west of the main outcrop, it is sometimes a matter of difficulty, as, for example, at Kedington in the Stour Valley, to refer the bed observed to its proper place in the geological sequence. The detrital minerals of the sands will usually be of service, and in the case quoted it was found that, while the Kedington deposit had the lithological characters, etc., of the Thanet Beds, its mineral composition showed it to be an outlier of Reading Beds, resting on the Chalk, but one which had been rearranged on the shore of the Crag sea. Cases might be multiplied, but the limited utility of the method must be apparent.

At present it is premature to discuss the question of the stability of minerals in geological time. The controversy upon the extent to which andalusite occurs in pre-Pliocene sediments in Western Europe is still fresh in our minds. The allied mineral, kyanite, appears to have a well-marked earlier limit in the English area, but how far the presence or absence is due to drainage direction is not certain. The extraordinary abundance of sharply crystalline apatite at a loamy horizon of the Thanet Beds near Ipswich, protected by a cover of Chalky Boulder-clay, is noteworthy as showing how an easily decomposable mineral may be preserved.

The investigation of sediments 'hermetically sealed' shortly after their formation, as, for example, gypsiferous deposits in the Permian and Trias, may by comparison yield interesting information as to the amount of decomposition which takes place in heavy minerals subsequently to their deposition.

[1] The disturbance referred to may be 150 yards long and 40 feet deep.

Oscillatory and alternating current action has an effect, not only in eliminating the more easily decomposable minerals (e.g. some of the ferromagnesian minerals, apatite, andalusite, etc.), but also in concentrating the heavy detritus by a kind of natural jigging or panning. 'Pay-streaks' may thus be produced. Parts of the pebble-bed under the London Clay in Suffolk exhibit an enrichment in zircon, rutile, ilmenite, and magnetite by this action, especially when there is evidence of current-action and contemporaneous erosion.

The lenticles of grains of titaniferous hæmatite occurring in the basal Cambrian conglomerates of St. Non's Bay, near St. David's,[1] may have a similar origin. The richness of the Bagshot Beds in the heaviest minerals may be attributed to a like cause.

As opposed to this concentration, we have the elimination of minerals (other than those which are more or less unstable) by conditions of deposit. The work of Thoulet and Retgers has shown that micas are absent from certain wind-formed deposits such as desert and dune sands, but examination of British blown-sand dunes has revealed their presence. Topaz tends to form flakes on account of its good basal cleavage, and may well float away; it has been suggested that andalusite may be lost in this way, by floating off during natural or artificial panning. The scarcity of apatite in many deposits is probably due to its disappearance by solution. It is more abundant in clays and loams than in sandstones where percolation is easy, but it does also occur in the latter. When the sediment has to be cleaned by long boiling with acid, much apatite undoubtedly dissolves, but, as in the case of the Boxstone Bed, some still remains. Professor C. G. Cullis and Professor W. G. Fearnsides have both suggested that the difference in solubility may be due to the presence of either or both chlor- or fluor-apatite, but usually the grains are so small, and the occurrence so uncommon, that micro-chemical proof is difficult.

What may be called the intensive study of an area of sedimentary rocks of various geological ages, surrounding an igneous or metamorphic complex, is at present very necessary for the advancement of our work on the petrology of sediments. For this purpose we need to know exactly and in detail the mineral composition of neighbouring crystalline rocks, slicing alone not being sufficient. Crushing must be resorted to, and panning and separation with heavy liquids, in order that we may be certain of knowing all the accessory and rarer minerals and their relative abundance.[2] Following this, the study of the neighbouring sediments of varying geological age, considered stratigraphically, cannot fail to yield valuable data which will serve to indicate the extent to which the differences observed in assemblages of detrital minerals may be caused by direction of drainage, conditions of deposition, stability of minerals in geological time, and contemporaneous or subsequent sealing of minerals in sedimentary rocks.

[1] W. Jones, Proc. Geol. Assoc., vol. xxii, p. 232, 1911.
[2] R. H. Rastall & W. H. Wilcockson, Proc. Geol. Soc., p. lxxx, 1915.

IV. Conclusion.

Detrital mineral assemblages are of considerable value for stratigraphical purposes over limited areas, but except for very broad divisions, as e.g. Eocene and Pliocene beds, cannot be used for wide correlations. Unlike fossils, minerals cannot show an evolutionary sequence or gradual variation, and there being comparatively so few species occurring in detrital sediments the number of combinations is very limited. Mineral suites, unlike life assemblages, therefore tend to recur. As in the case of minerals of igneous rocks, the relative abundance of the heavy components in sediments is of great determinative value. Mere lists of detrital minerals occurring in sediments are therefore not sufficient; we need to know the size, colour, form, degree of alteration (if any), and other characters of each mineral, as well as its relative abundance.

The zonal value of mechanical and mineral analyses has not yet been determined, partly because the rocks which yield the best heavy mineral crops, such as sandstones, loams, etc., do not lend themselves to zoning by fossils, while the clays and limestones, which often contain valuable life assemblages, contain frequently only a very small quantity of heavy minerals (other than authigenic). The connexion between the mechanical composition (e.g. of clays), as indicating differences in condition of deposit, and the contained faunas of various zones, has yet to be worked out, but the results may well be interesting.

The goal to be aimed at is a knowledge of the mineral and mechanical composition of every sedimentary rock in the British geological column, collection of material being made over as wide an area as possible. Cores of borings, as well as the records only, must be carefully preserved, and the beds met with subjected to similar analyses. The information obtained should be correlated with that yielded by the distribution of isopachytes and sub-surface contours.

V.—Sedgwick Museum Notes.

Notes on the genus *Trinucleus*. Part IV.

By F. R. Cowper Reed, M.A., Sc.D., F.G.S.

(*Concluded from the March Number, p. 123.*)

Morphological Correlations.

WE have now finished the survey of the characters of the head-shield of *Trinucleus* sufficiently to enable us to discuss the vexed questions of the affinities, systematic position, and evolution of the genus; and from the foregoing details of the various species we can perceive that there are many difficult problems presented when we attempt to correlate its structure with that of other trilobites. Whether the peculiar characters of the genus are the result of degeneration or of the persistent retention of early phylogenetic stages or of a reversion to such stages is a matter of dispute.

Lake,[1] in regarding the genus *Orometopus* as the earliest genus of the Trinucleidæ, concluded that it was not improbable that the ocelli in *Trinucleus* represented normal compound eyes in a degenerate condition. Swinnerton[2] is also inclined to regard the absence of normal facial sutures and eyes not as a sign of early phylogenetic position but as secondary modifications of the Opisthoparian type of head-shield. For he does not consider the marginal suture as homologous with the facial sutures of the Opisthoparia and Proparia. These views are diametrically opposed to those put forward by Beecher,[3] on which the classification of the trilobites has of late years been based.

It may be pointed out that the present author, in 1898,[4] drew attention to the importance of adaptive changes in trilobites in connection with the loss of eyes and to the modifications of the head-shield which accompanied this loss, and it was maintained that blindness was not by itself any evidence of primitive phylogenetic position or of reversion to early stages of development. In the case of *Trinucleus* blindness was considered to be an adaptation to special environment. Dollo[5] has treated this subject at considerable length, and has concluded that *T. concentricus* lived in the mud under aphotic conditions as a member of the benthos.

1. *Facial Sutures and Genal Areas.*

The controversy as to the presence or absence of facial sutures crossing the genal areas (apart from the marginal suture round the fringe) has been waged by many palæontologists.[6] But no satisfactory evidence of the occurrence of such sutures in young or adult has been produced, and McCoy's[7] figures and description of their presence in his genus *Tretaspis* are not supported by an examination of the specimens which he used. It is needless to recapitulate here the opinions of the various writers on the subject, for in the case of the English species here studied it has been possible for me to test the accuracy of their observations and conclusions. The line of inquiry which they followed was not often comparative, and the principles of development were not understood by the earlier investigators. The researches of Beecher and other American workers have thrown a flood of light on the ontogeny and phylogeny of the trilobites, and from the adoption of the principles which they have established the position of *Trinucleus* has been regarded as fairly secure amongst the most primitive group, Hypoparia. But recently, as above remarked, signs of dissatisfaction with this conclusion have been apparent.

If we regard the genus as now possessing degenerate characters which it has acquired by the loss of certain structures, such as facial

[1] Lake, *Cambrian Trilobites* (Palæont. Soc.), 1907, p. 45.
[2] Swinnerton, GEOL. MAG., Dec. VI, Vol. II, p. 489, 1915.
[3] Beecher, Amer. Journ. Sci., ser. IV, vol. iii, pp. 89–106, 181–207, 1897.
[4] Reed, GEOL. MAG., Dec. IV, Vol. V, pp. 439–47, 552–9, 1898.
[5] Dollo, Bull. Soc. Géol. Belgique, xxiii, p. 417, 1909.
[6] Woods, article on Trilobita in *The Cambridge Natural History*, vol. iv, Crustacea, pp. 226, 230–1, 244–5, 1909.
[7] McCoy, Syn. Brit. Pal. Foss. Woodw. Mus., p. 146.

sutures and compound eyes, we should naturally turn to its earliest representatives for traces of these structures. It is in the first group, comprising *T. Murchisoni*, *T. Gibbsi*, and *T. Etheridgei*, that the division of the genal areas by an oblique ridge is found, and this ridge has the course of the true facial suture in members of the Opisthoparia, and may possibly be regarded as marking the line of fusion between the free and fixed cheeks. The less modified stage in which fusion has not taken place would then be found in the genus *Ampyx*. In neither case are traces of compound eyes present along this line. The similar position of the pseudo-antennary pit in this genus and in *Trinucleus* supports this comparison. Some species of *Ampyx* (e.g. *A. nudus*) also have oblique nervures originating from the same place in the axial furrows as in *Trinucleus*, and running obliquely back across the cheek to the point of section of the posterior margin by the facial suture, which suggests that they are structures similar to the radiating nervures in *T. Murchisoni*, and to the posterior or outer part of the ocular ridge beyond the ocellus in the *T. seticornis* group.

In the Conocoryphidæ (Eastman-Zittel, 1913), in which compound eyes and ocelli are absent, but in which narrow free cheeks are found separated off by true oblique facial sutures, there are groups of nervures radiating out from the same place on the axial furrows as in *Trinucleus*. This diffuse innervation of the genal areas is a conspicuous feature amongst blind trilobites, and is especially developed in *Liocephalus*[1] of the Conocoryphidæ and in *Dionide*. The loss of eyes is found to be correlated with the straightening of the facial sutures and reduction in width and size of the free cheeks in higher genera (e.g. some species of *Illænus*[2] and *Trimerocephalus*)[3]; or the facial sutures may entirely disappear by coalescence of the free and fixed cheeks, as in *Typhloniscus*[4] and some species of *Phacops*.[5]

2. *Fringe.*

A difficulty meets us at this stage when we cease to regard the marginal suture on the edge of the fringe as representing the conjoint facial sutures as in Beecher's theory, for the question of its correlation has to be faced. In answer to this we may suggest that it is possible that the lower plate of the fringe represents a reflexed anterior segment of the head-shield, and that the marginal suture is the divisional line between this and the first segment of the superior surface. The bending round ventrally of the anterior part of the crustacean head in its phylogenetic development is part of Bernard's[6] annelidan theory of the origin of the Crustacea. Bernard held that while the typical Crustacean head only consisted of five somites some of the trilobites possessed six somites in the cephalic shield. Early

[1] Grönwall, *Bornholms Paradoxideslag* (Danmarks geol. Undersog., ii, No. 13), 1902, p. 102, t. 2, fig. 2.

[2] Reed, Q.J.G.S., vol. lii, pp. 414–16, pl. xx, figs. 1–3, 1896.

[3] Gurich, Verh. Kais. min. Ges. St. Petersb., ser. II, Bd. xxxii, p. 359, t. xv, figs. 7*a*, *b*, 1896.

[4] Reed, GEOL. MAG., Dec. V, Vol. V, p. 433, pl. xiv, figs. 1–3, 1908.

[5] Gurich, op. cit., p. 362, t. xv, figs. 4*a*, *b*.

[6] Bernard, Q.J.G.S., vol. l, p. 411, 1894.

trilobites nearer the annelidan stock and with less fixed ordinal characters might have more segments bent round ventrally than higher forms, and the degree of coalescence of these inverted segments might vary. Thus, in the protaspis of *Triarthrus* there are two segments in front of the glabella which does not reach the anterior margin as it does in *Sao*; and if the immediate ancestors of *Trinucleus* had such additional anterior somites one of them might have given rise to the "lower plate", which, with its genal spines, would thus constitute an exceptionally modified and unfused segment. The condition of the adult head-shield of *Trinucleus* would thus have retained more primitive features than any other trilobite.—We must admit that the ontogeny of *T. concentricus*, so far as it is known, does not support this theory, but we must remember that the larval stages of the earliest species of *Trinucleus* are unknown, and we have been led from previous considerations to regard *T. concentricus* as one of the more specialized forms. In some other trilobites also the somite represented by the free cheeks (the so-called "ocular segment" of Walcott) might not be the first one in the composition of the cephalic shield.

The rostral suture of *Calymene* and other genera on the above theory might be regarded as the abbreviated representative of the same suture as the marginal one in *Trinucleus*, and the epistome as corresponding to the lower plate of the fringe.

Walcott,[1] by his study of the Mesonacidæ, has been led to consider it as not improbable that a seventh segment more anterior than the "ocular segment" (i.e. the segment comprising the free cheeks and carrying the compound eyes) existed in the primitive cephalon of the Mesonacidæ, and he sees traces of it in the larval structure of *Olenellus Gilberti* and in the cephalon of *Olenelloides* and *Callavia bicensis*; so that in tabulating the somites included in the cephalon he gives first the "anterior border segment", secondly the "ocular segment", and thirdly the first glabellar segment from which the ocular ridge and palpebral lobe are developed.

It may here be mentioned that though the genal spines belong to the "ocular segment" in the Opisthoparia, yet in the Proparia they belong to one of the posterior segments and perhaps to the fourth glabellar segment of the Mesonacidæ, which in some genera (e.g. *Olenelloides*) is produced at its lateral termination to form the so-called intergenal spines on the posterior border. The genal spines of the Proparia are therefore not homologous structures with those of the Opisthoparia, a point of importance rarely recognized; and it would therefore not be wholly contrary to expectation to find the genal spines of the genus *Trinucleus* belonging to a different somite of the cephalon, and possibly to the first or "anterior border" one of Walcott, bent under ventrally.

Whatever value may be attached to the above theoretical considerations, it must be admitted that there is a possible interpretation on these lines, though it would upset our whole accepted ideas of the morphological correlation of the parts of the head-shield.

Another suggestion which may be offered to explain the marginal suture is that it is connected with the process of ecdysis; for *Limulus*

[1] Walcott, Smithsonian Misc. Coll., vol. liii, No. 6, p. 238, 1910.

and *Apus* are said to moult by splitting along the frontal edge of the carapace. This would then have to be regarded as a special adaptation, and perhaps of no phylogenetic importance. The facial sutures in trilobites are usually considered to have been of some use in ecdysis, and compensation for their loss in *Trinucleus* may have been obtained by this means.

The fringe would according to this hypothesis be merely brought about by the flattening and broadening of the ordinary cephalic border, while the perforations through its substance might be derived from the multiplication of pits similar to those seen in the marginal furrow of *Dionide*,[1] *Harpes*, and *Euloma*.[2] The lower plate of the fringe would represent the doublure or reflexed portion of the border. The complete fusion of the pits of the upper and lower surfaces of the fringe would be secondary.

3. *Ocular Ridges and Nervures.*

The history and relations of the "ocular ridge" or "eye-line" in *Trinucleus* now demand attention. It is generally looked upon as a primitive character. Walcott (op. cit.) has shown how it forms part of the third cephalic (i.e. first glabellar) segment in the case of the Mesonacidæ; and in Cambrian trilobites belonging to the Opisthoparia as well as to the Harpedidæ this structure is well developed, while, as is well known, it persists in some later genera. It is usually accepted without question that the similarly named structure in *Trinucleus* is homologous with this "eye-line" of the Olenidæ, etc., though in the latter its point of origin does not appear to be so constant, for it frequently arises close to the anterior end of the glabella instead of strictly opposite the first glabellar furrow. It also runs out to compound eyes, not to ocelli, and the eyes are situated on the facial sutures. It is remarkable that in the earliest representatives of the genus *Trinucleus* (Group 1) the typical ocular ridge does not occur; but it is found in the larval stages of *T. concentricus*, and is well developed in the adult of *T. seticornis* of our second group. Till we know the ontogeny of *T. Murchisoni* or its allies we cannot come to the conclusion that the irregular radiating bunch of nervures is more primitive than the definite ocular ridge or optic nerve, at any rate in this genus. But the stratigraphical succession of species points this way, if we dismiss the idea of degeneration.

In most of the Conocoryphidæ[3] (e.g. *C. Sulzeri*, Schloth., and *Erinnys venulosa*, Salt.) there is one of the nervures more strongly developed than the rest, and it forms the trunk from which they branch; its position corresponds with that of the eye-line of the Olenidæ. If we regard the ocelli of *Trinucleus* of Group 2 to be the degenerate successors of the compound eyes of other trilobites and believe that the facial sutures have been obliterated by the complete fusion of the free and fixed cheeks, there is no difficulty in accepting the view supported by Lake and Swinnerton (op. cit.) that the ocular

[1] Reed, GEOL. MAG., Dec. V, Vol. IX, p. 200, Pl. XI, Figs. 3-6, 1912.

[2] Brögger, *Die Silur. Etagen 2 und 3* (1882), p. 98; Reed, GEOL. MAG., Dec. IV, Vol. VII (1900), pp. 251, 255.

[3] Grönwall, *Bornholms Paradoxideslag*, pp. 82-104, 1902.

ridges in *Trinucleus* are homologous with those in other genera, such as members of the Olenidæ. But if we maintain that the marginal suture represents the facial sutures, great difficulties seem to be introduced. For the relics or rudiments of the compound eyes, according to Beecher's theory, would then have to be sought at the edge or below the edge of the fringe, and the ocular ridges as they now exist must have been shortened considerably. The ocelli then would not be placed at the original terminations of these "eye-lines" but somewhere along their course, and could not be homologous in position or origin with the compound eyes. The larval characters of *T. concentricus*, which has the ocular ridge and tubercle developed, do not lend any support to the view that the ocular ridges have been reduced in length and are shrunken remnants of longer ridges. Thus we see another line of evidence tending to contradict Beecher's theory.

4. *Eyes.*

The absence of eyes in genera of the higher families is found to be accompanied by modifications in the head-shield on the same lines (apart from the development of a fringe), and no genetic deductions can be drawn from this want of visual organs. In the Illænidæ, Phacopidæ, and Cheiruridæ we find instances of their absence.

On the other hand, the presence of compound eyes is not invariably associated with the retention of facial sutures, as we find in the case of certain species of *Acidaspis*, in which the sutures have been obliterated or lost by the coalescence of the free and fixed cheeks.

The extension of the ocular ridge to the postero-lateral angle of the genal area may find its explanation in the continuation of the same structure on the "ocular segment" in larval forms and some adults of the Mesonacidæ, and if this is a correct view it would mark the original course of the posterior branch of the facial suture. There is, however, another explanation possible by which we could regard it as merely the result of the concentration of those nervures which we found in some of the early species of *Trinucleus* convergently trending to this angle. The enlargement of one nerve at the expense of the others in this outer portion of the genal area may have taken place contemporaneously with the development of the ocular ridge from the axial furrow to the ocellus. And in support of this view we find traces of a similar strong nervure in *Ampyx nudus*, which has a facial suture placed much further out and independent of it.

It may be here mentioned that no lenses have yet been detected in the so-called ocelli of any species of *Trinucleus*, though they are well developed in *Harpes* and are schizochroal. The visual function of these genal tubercles in *Trinucleus* is generally assumed, but it may be that they had some other sensory function, or that their visual powers (if they are regarded as degenerate compound eyes) have become obsolete. The tubercle on the pseudo-frontal lobe of the glabella, which is generally present in *Trinucleus*, and has precisely the same appearance as those on the cheeks, may be representative of the "dorsal organ" of the Phyllopods, which is supposed to be excretory rather than sensory in its function. But it may represent a median unpaired ocellus, and it is frequently present in species which have

no genal tubercles, though in some cases it appears to be completely absent.

5. *Specialization.*

It is not only in the head-shield of *Trinucleus* that we can observe extraordinary specialization and the modification or loss of phylogenetically primitive characters. For the small and constant number of the thoracic segments, and the uniform type of pygidium as well as its relatively large size and its composition of many fused segments, indicate a considerable divergence from and advance beyond the condition of the many-ringed thorax and small pygidium of the Conocoryphidæ and Olenidæ or even the Harpedidæ, in spite of the latter having often been regarded as closely allied to *Trinucleus*.

It does not seem that *Trinucleus* is in the direct line of any of the other groups of trilobites, but was an early offshoot of the Opisthoparia, to which it is linked (though not by direct phylogenetic connection) by *Orometopus* and especially *Ampyx*. Its nearest homœomorphs are *Dionide* and *Harpes*, but the latter retains more of the primitive trilobite characters (e.g. many segments to the thorax and a small pygidium), and does not show such extreme specialization except in the head-shield.

Instead, therefore, of placing *Trinucleus* as one of the simple lowly types of trilobites illustrating an early stage in the history of the class, it seems more probable that we should regard it as a modified and degenerate form belonging to the Opisthoparia which has been specialized and adapted to a peculiar environment.

Summing up the results of our study of the head-shield of *Trinucleus* and balancing the probabilities of the various theories in connection with its structure and origin, we seem led to conclude that the ancestors of this genus branched off from an Opisthoparian stock and suffered degeneration of certain parts in combination with extreme specialization of other parts to fit them for a peculiar environment. Under the aphotic condition of the benthos burrowing in the mud rendered compound eyes unnecessary and they therefore degenerated, while in compensation for the loss of these organs a complete system of nervures developed over the glabella and cheeks. The fixed and free cheeks fused along the line of the facial sutures and ultimately became completely obliterated. The border of the head-shield broadened out and was folded in ventrally so as to form a lower plate, while to facilitate moulting a line of fission was formed along its edge. Perforation of both layers of this border took place on an extensive scale, and the corresponding pits of the two layers frequently communicated. A change of habits in some of the species led to the development of ocelli by rudiments of the compound eyes persisting from larval to adult life, but in other cases this renewal of visual organs was found of no value, and therefore again lost. In conjunction with the presence of the ocelli the optic nerve (ocular ridge) was strengthened and redefined. These changes, which suggest the retention till maturity of larval features or the re-acquisition of organs of which the rudiments had only been left, do not appear to have been strictly successional, but to have been developed as occasion required.

P.S.—Since the above was written Professor Swinnerton's concluding paper on the classification of the Trilobites has been issued (GEOL. MAG., Dec. VI, Vol. II, p. 543, December, 1915). In it the three families Trinucleidæ, Raphiophoridæ, and Harpedidæ are placed in a separate sub-order with three other families as a provisional appendix, and their line of descent is traced back to a Conocoryphid-like stock. This view is in general accordance with my conclusion that *Trinucleus* is more probably connected with the Opisthoparia than with the ill-established group Hypoparia.

REVIEWS.

I.—RADIO-ACTIVITY AND GEOLOGY.

THE BIRTH-TIME OF THE WORLD, AND OTHER SCIENTIFIC ESSAYS. By J. JOLY, M.A., Sc.D., F.R.S. pp. 307. T. Fisher Unwin. 1915. 10*s.* 6*d.* net.

THIS volume is an eloquent witness to the love which its versatile author feels for all the activities of nature. It contains twelve essays, mostly written during the last few years, dealing not only with geological problems but also with such diverse subjects as the abundance of life, the colours of flowers, the 'canals' of Mars, the photographic image, the application of radium to medicine, and the physics of skating. These last are mentioned only to show the far-flung interests of Professor Joly and the broad appeal of his book; for it will be convenient to restrict the discussion in this place to those of the essays which are specifically geological: The Birth-time of the World, Denudation, Mountain Genesis, Alpine Structure, and Pleochroic Haloes. The problems considered fall approximately into two categories. First, the measurement of geological time by denudational and radio-active processes, and second, the genesis of mountains. Pleochroic haloes, their explanation, and their application to determining the age of the minerals in which they occur, form the subject of a delightful essay which is already so well known that it calls for no comment here, but one of admiration.

Some of the results obtained by Professor Joly for the age of the earth, based on geological methods, are as follows:—

1.	From the thickness of sediments . .	100–134 million years.
2.	,, mass of sediments . .	87 ,, ,,
3.	,, sodium in the ocean . .	99–105 ,, ,,

It is unfortunate that the data used in arriving at an estimate of the detritus borne by the rivers to the sea do not include the recent results for the whole of the United States (Dole & Stabler, Water Sup. Pap., U.S.G.S., No. 234, 1910). In the light of this work the figure given for the annual increment of sediment—10,700 million tonnes, + 11 per cent for bottom load—seems to be much too high. Here it may be mentioned that Professor Joly uses the term "sedimentary rock" where mechanically transported detritus is meant, as, for example, when he states that "100 tons of igneous rock yields rather

less than 70 tons of sedimentary rock" (p. 43). Actually, of course, more than 100 tons of sedimentary rock are produced, because most of the materials carried in solution to the ocean are afterwards incorporated by sediments, and, moreover, a good deal of material is abstracted from the atmosphere during the process of weathering. However, since the same meaning is consistently assigned to "sedimentary rocks" throughout the calculations, no error is thus introduced in the time estimates.

The amount of sodium annually contributed to the ocean is given as 175 million tons. This figure implies that the sediments now undergoing solvent denudation must lose all the sodium they contain, for the average amount of sodium in sediments, as exposed on the lands, is only 0·85 per cent. Unless, indeed, the igneous and other crystalline rocks of the earth's surface—and these do not cover more than a quarter of the land areas—also lose all their sodium (and we know they do not), then the sediments must lose more than they appear to have originally contained. This remarkable discrepancy shows either that the statistics of denudation are wrong, or that solvent denudation is now far more active than it has been on an average in the past, or that sodium is in some way restored to the sediments from sea-water. The latter possibility, exemplified by wind-borne salt, is further suggested as probable by the presence of salt waters in deep mines, and by phenomena of adsorption, whereby oceanic salts would become concentrated and trapped in sediments while they yet lay on the sea-floor. That denudation may be unusually active at the present time is a view that Professor Joly does not support. In favour of his contention to the contrary, he quotes figures to show that Europe, with the lowest average elevation among the continents, is undergoing the most rapid denudation. However, it is just in Europe that agricultural pursuits have been longest followed, and who can doubt that agricultural processes may enormously add to the ease with which the natural agents of denudation can attack the land. In the case of the other continents there does appear to be a relation between mean elevation and total denudation. In so far, therefore, as the continents and mountain ranges stand higher to-day than they have averaged in the past, we may expect the intensity of denudation to be correspondingly increased. The remaining possibility, that the statistics of denudation are wrong, only enhances the difficulty, for when the United States data are added to those already available, the amount of detritus is found to be less than Joly gives, while the amount of sodium remains practically the same. It is possible, however, that owing to the difficulty of estimating sodium in river waters, errors may arise from inaccuracies of analysis.

If the geological methods of measuring time as interpreted by Professor Joly are reliable, then it is necessary to show in what way the radio-active estimates are wrong. The latter give for the earliest known igneous rocks an age of about 1,500 million years. The pleochroic halo method gives a most probable value of 400 million years for the Leinster Granite (late Silurian or early Devonian).

Professor Joly throws out the suggestion that the rate of transformation of uranium may have been in the past more rapid than now. This, of course, if it could in any way be demonstrated, would necessitate a reduction of the time estimates based on such transformation. The suggestion can, however, be tested in another way, for if the rate of transformation were formerly more rapid than now, then the amount of energy liberated during any given period of the past would also be greater than now. That is to say, if the earth has cooled from a high temperature such as 1,000° C. at or near the surface, the radiothermal energy must have retarded the rate of cooling in the past more than it does now. Under these circumstances, if the earth were able to cool at all, it would certainly cool so slowly that its age would be much higher than the 1,500 million years required by the accumulation of lead. Joly's suggestion, then, is incompatible with belief in an earth originally molten at or near the surface. Since no basement has ever yet been found at the bottom of the geological succession that has not been molten at some time or other, the period required for cooling down to present conditions must have been even greater than that demanded by uninterrupted cooling from a molten state. Thus, the assumption that radio-active transformations have not been uniform leads to far more serious difficulties than does the alternative view that geological processes have not been uniform.

In his essays on mountain genesis and structure, Professor Joly introduces a less controversial subject. He shows that the accumulation of sediments leads not only to thermal blanketing of the rocks beneath, but also to an additional rise of temperature due to the emission of heat from the radio-elements contained in those sediments. In this way, thick lens of sediments and the rocks below them become so weakened by the rising temperature that when the earth contracts they are folded and upheaved by compression, in preference to cooler and more rigid portions of the crust. The process is worked out in convincing detail, and there can be no doubt that Professor Joly has added to the theory of mountain-building a most significant contribution.

Before closing this review, which by no means covers the whole scope of the book, the writer feels that he should express the pleasure that he has experienced in reading so admirable a collection of essays. The rhythm of life, the majesty of the mountains, the inner secrets of the rocks, and the stimulating companionship of nature—all are revealed in its pages, and reflected in the beautiful photographs with which they are illustrated.

ARTHUR HOLMES.

II.—FIELD ANALYSIS OF MINERALS. By G. D. McGRIGOR. *The Mining Magazine*, pp. 86. 1915. 3*s*. 6*d*. net.

THIS book has been written professedly to meet the requirements of the traveller and prospector, and in keeping with that purpose it has been published in a size convenient for the pocket. The advantages of a small strongly bound book in the field may readily be granted, but when the author, in his "Prefatory Remarks and Advice", recommends the traveller also to take with him Brush

and Penfield's bulky *Manual* and Rutley's *Elements of Mineralogy*, one wonders why the smaller book should have been compiled at all. Certainly it only claims to deal with analysis, but analysis *alone* is generally a cumbersome and sometimes an insufficient means of determining minerals. As a supplement to the many excellent books on determinative mineralogy which already deal with blowpipe analysis (such, for example, as those noticed below) this little handbook can claim at best only a very limited field. Unnecessary space is devoted to wet methods of analysis, and this might have been better occupied by lists of minerals with their composition and simpler properties. Microcosmic salt is said to be commonly termed 'micro'; sodium carbonate is referred to as 'soda'; the use of the scale of hardness is mentioned, though the scale itself is not given.

III.—Determinative Mineralogy. By J. V. Lewis. Wiley & Sons. 2nd ed., revised. pp. 155. 1915. Price 6*s.* 6*d.* net.

THIS edition differs from the first in no essential particulars, but it is improved by the addition of several new features that greatly enhance its usefulness. A number of delicate tests have been introduced for various elements or minerals, and the determinative tables have been made more complete. The only blemish that disfigures the pages of the book consists in the use of a large number of abbreviations, many of which are not only ugly but, if saving of space was the ideal sought after, quite unnecessary. The index is good, and the references to any mineral can be located with ease.

IV.—Elements of Mineralogy. By Frank Rutley; revised by H. H. Read; introduction by G. T. Holloway. Murby & Co. 19th ed. pp. 394. 1916. Price 3*s.* 6*d.* net.

RUTLEY'S well-known book has long been a favourite; among students for its cheapness, among teachers for its thoroughness and general accuracy, and among prospectors for its completeness and convenient size. If this was true of the old 'Rutley', then the present revised and largely rewritten edition ought to enjoy a still higher degree of popularity. Not only is the work brought completely up to date, but the presentation of the facts and the aspect of each printed page is much more attractive than formerly. The inclusion of a chapter on optical properties and its application to the determination of the silicate minerals will be much appreciated. The economic side of mineralogy is given considerable prominence, and attention is directed to the mode of occurrence and uses of minerals rather than to localities alone. The arrangement of minerals according to their most noteworthy element has many advantages, especially from the point of view of determination and economics. In each case an introduction to the element in question is provided, including a list of the chief minerals into which it enters. The book concludes with a useful glossary, a table of the geological systems, and a very complete index. Reviser and publisher are alike to be congratulated on their success in building on the sound foundation of Rutley a most valuable and comprehensive work.

V.—The Epigene Profiles of the Desert. By A. C. Lawson. University of California Publications, Bull. Dept. Geol., vol. ix, No. 3, pp. 23–48, 1915.

THE author discusses the effects of arid erosion on an uplifted land mass, and explains the origin of the three elements that enter into the profile thus evolved—rock slopes having an angle of less than 35°, alluvial fans with slopes rarely exceeding 5°, and widespread plains. The area to which the paper chiefly refers is that of the Great Basin, in which wind scour is held to be "an extremely inefficient agent in the evolution of the . . . relief". The encroachment of alluvial embankments on the rocky slopes is attributed to mechanical disintegration, while scanty rains and occasional cloudbursts sweep the detritus to lower levels. Ultimately the cycle culminates in the 'panfan'—a vast alluvial surface of aggradation below which all rock slopes have at last been buried. As corrasion and deflation are dismissed as unimportant, the paper must be regarded as applying to a particular desert rather than to deserts in general.

VI.—Brief Notices.

1. Triassic Rocks of Wirral.—Messrs. Greenwood & Travis have given us part ii of their paper on the Mineralogical and Chemical Constitution of the Triassic Rocks of Wirral. The paper appears, like part i, in the Proc. Liverpool Geol. Soc. (xii (2), 161–88, 1915), and deals with the chemical side. The authors arrive at the general conclusions (1) that the material of the Wirral Trias, as a whole, was derived from igneous rocks of a granitoid nature; (2) that the Bunter and Keuper differ in the physical conditions of the grains, but agree in containing the same minerals; (3) that the Keuper was probably derived direct from the disintegration products of an igneous mass; and (4) that the Bunter had previously formed part of an earlier arenaceous rock-mass.

2. A New Method in Zoogeography.—The study of geographical distribution is so intimately bound up with palæogeography, and therefore with geology, that we make no apology for directing the attention of our readers to an important paper by Mr. R. J. Tillyard, M.A., of Hornsby, N.S.W., "On the Study of Zoogeographical Regions by means of Specific Contours" (Proc. Linn. Soc. N.S. Wales, vol. xxxix, pp. 21–43, pl. i, 1914). Taking a well-defined group, Mr. Tillyard plots down the number of species recorded from all known localities, and calls the lines bounding tracts with the same number "specific contours". He illustrates his method by applying it to the dragonflies of Australia, with interesting results. Another paper by Mr. Tillyard is a "Study of the Odonata of Tasmania in relation to the Bassian Isthmus", that portion of land which once (but when?) connected Tasmania with the Australian mainland (op. cit., vol. xxxviii, pp. 765–78).

3. The Form and Constitution of the Earth.—An interesting paper by L. B. Stewart delivered as the Presidential Address to the

Royal Astronomical Society of Canada in 1914 (reprinted Smithsonian Rep. for 1914 (1915), pp. 161–74) summarizes recent geodetic work on the form and constitution of the earth. The paper consists mainly of an account of the gradual measurement of the size of the earth, and finally discusses isostasy and allied problems. He accepts isostasy, and adopts the view that the earth is a cooling and shrinking body of which the crust accordingly is under the continual necessity of adapting itself to smaller space; and to this contraction he attributes earthquakes, and as probably none of them originate at a greater depth, he concludes the material at greater depths behaves as a fluid. He also holds the view that the earth as a whole is more rigid than steel. He summarizes the conclusions as to the rate of earthquake waves at different depths.

4. Shallow-water Deposition in the Cambrian of the Canadian Cordillera.—Under this title Mr. L. D. Burling publishes in the *Ottowa Naturalist* for November, 1915, evidence of shallow-water conditions during the deposition of Cambrian limestones in British Columbia and Alberta. Such evidences are mud-cracks, ripple-marks, and interformational conglomerate. Such proofs occur in the Middle Cambrian Mount Stephen formation, though not, of course, in the Burgess Shales; also at the base of the Upper Cambrian, in the Bosworth formation, where also are large casts of salt crystals.

5. The Faunistic Influence of Lithological Character.—Mr. L. D. Burling (Bull. Geol. Soc. America, vol. xxv, p. 421) has studied the relation of the genera and species of Brachiopoda to the sediments in which they are found, so far as concerns the Cambrian and Lower Ordovician rocks mainly in North America. Dividing sediments into shale, sandstone, and limestone, he finds that 41 per cent of the genera and sub-genera, 74 per cent of the species and varieties, appear to have been identified from but one type of sediment. About half of these, however, are represented by single species in single faunules or localities. Although the nature of the sea-floor does thus appear to exert some influence on the nature and number of the species (there are fewest in shale, most in limestone), still most species can accommodate themselves to changes in the character of the sediment, especially when the change is from more to less elastic. The study is of enough importance to be extended to other groups of animals.

6. Geologists' Association of London.—Mr. George W. Young ended his presidency of this body on February 4, when he read his second annual address "On the Geological History of Flying". This year he dealt with Invertebrates, last year with Vertebrates. Mr. George Barrowe (late of H.M. Geological Survey) succeeded to the presidential chair. The usual list of proposed excursions is issued, many close to London and of exceptional interest. The 'long excursions' have not yet been fixed.

7. The Zoological Record.—The annual volume for 1914 (vol. li) has just appeared. Palæontologists may be reminded that all fossil forms are included, and that the literature of each group is published separately at a small cost. At the present moment the Zoological

Record is the only list available for 1914. That for 1915 is in preparation, and a list of the parts can be obtained from the Secretary of the Zoological Society.

8.—Obsidian from Hrafntinnuhryggur, Iceland: its Lithophysæ and Surface Markings. By F. E. Wright. Bull. Geol. Soc. Am., vol. xxvi, pp. 255–86, 1915.

In his work on the Obsidian Cliff spherulites, Iddings came to the conclusion that the expansion of liberated gases played little part in the development of lithophysæ. The examples studied by Dr. Wright indicate, on the contrary, that the volatile components liberated with the radial crystallization of the spherulites "aided materially in the original formation and subsequent enlargement of the lithophysal cavities". Other structures are also discussed, notably surface pits and grooves etched by hot circulating solutions, which bear a striking resemblance to the surface markings of moldavites. While the terrestrial origin of the latter is not proved, it is shown that their external form and internal strains afford no evidence of an extra-terrestrial origin.

REPORTS AND PROCEEDINGS.

I.—Geological Society of London.

Annual General Meeting.

February 18, 1916.—Dr. A. Smith Woodward, F.R.S., President, in the Chair.

The Reports of the Council and the Library Committee, proofs of which had been previously distributed to the Fellows, were read. It was stated that of the 31 Fellows elected in 1915 (6 less than in 1914), 23 paid their Admission Fees before the end of that year, making, with 8 previously elected Fellows, a total accession of 31 in the course of 1915. During the same period, the losses by death, resignation, and removal amounted to 90 (34 more than in 1914), the actual decrease in the number of Fellows being, therefore 59 (as compared with a decrease of 11 in 1914). The total number of Fellows on December 31, 1915, was 1,250.

The Balance-sheet for that year showed receipts to the amount of £2,836 2*s*. 10*d*. (excluding the balance of £105 18*s*. 5*d*. brought forward from 1914), and an expenditure of £2,306 7*s*. 11*d*.

Reference was made to the fact that three out of the four members of the staff of permanent officers were still engaged in various duties under the War Office, and that temporary assistants had consequently been appointed.

The decease of the former Assistant Librarian, Mr. William Rupert Jones,[1] was announced, and the awards of the various Medals and Proceeds of Donation Funds[2] in the gifts of the Council were enumerated.

[1] See Obituary, Geol. Mag., February, 1916, p. 96.
[2] See brief report, Geol. Mag., March, 1916, p. 135.

The Report having been received, the President handed the Wollaston Medal, awarded to Dr. Alexander Petrovich Karpinsky, to M. Constantin Nabokoff, Councillor of the Imperial Russian Embassy, addressing him as follows:—

Councillor NABOKOFF,—The Council of the Geological Society has this year awarded the Wollaston Medal, its highest distinction, to Dr. Alexander P. Karpinsky, Honorary Director of the Geological Committee of Petrograd, which is responsible for the geological survey of the Russian Empire. Dr. Karpinsky's activities have extended over a period of more than forty years, and so long ago as 1874 he made one of his most important discoveries, that of a marine formation in the Ural Mountains intermediate between the Carboniferous and the Permian Systems. This Artinskian Stage, as Dr. Karpinsky termed it, has now been traced in Russia almost from the Arctic Ocean to the Caspian Sea, besides being recognized in more remote regions, as in the Salt Range of India. Its interesting fauna has also been the subject of several important monographs, of which one of the most valuable is that on the Ammonoids, contributed by Dr. Karpinsky himself to the Imperial Academy of Sciences of Petrograd in 1889. Dr. Karpinsky has continued to take the deepest interest in the geological problems presented by the Urals, and has treated them with remarkable versatility from every point of view, whether tectonic, petrographical, or palæontological; but as official director of the surveys from 1885 to 1903 he also extended his researches to many other districts, and took a prominent part in the preparation of the beautiful geological maps which were issued during his period of active service. The useful Geological Map of Russia in Europe, which he edited in 1893, is especially well known. All Dr. Karpinsky's work is characterized by the most painstaking thoroughness, of which I need only cite his two exhaustive memoirs on the Carboniferous ichthyolite, *Helicoprion*, as conspicuous examples. Those who have the privilege of his personal acquaintance recognize in him an unassuming and enthusiastic student, still absorbed in following and aiding the progress of our science, and pre-eminently one whom the Geological Society delights to honour.

The Council will be glad if you will convey this medal to Dr. Karpinsky as a token of its esteem and admiration, with an expression of its best wishes.

Councillor Nabokoff replied in the following words:—

Please accept my sincere thanks for the honour that you have done me in asking me to come here to-day and to convey to Dr. Karpinsky, with the expression of your good wishes, the Wollaston Medal which the Council of the Geological Society has awarded to him. I feel certain that this great distinction will be deeply appreciated by the recipient of the medal, as well as by the Russian Geological Committee as a high tribute to their Director. My distinguished friend, Dr. H. H. Hayden, Director of the Geological Survey of India, who crossed the Pamirs from India into Russian Turkestan a few months before the War, has often expressed to me the wish and hope that the highly interesting and valuable scientific researches which have been carried out on both sides of the Pamirs by the British and Russian geologists may be linked up and conducted on a basis of firmer and more complete unity and co-ordination. I venture to avail myself of this opportunity of expressing on behalf of my countrymen the same wish, and the confident hope that the ties of friendship which now unite Britain and Russia may extend from the fields of battle to the lofty peaks of science and enlightenment.

The President then handed the Murchison Medal, awarded to Dr. Robert Kidston, F.R.S., to Dr. Finlay Lorimer Kitchin, M.A., for transmission to the recipient, and addressed him as follows:—

Dr. KITCHIN,—The Council has awarded to Dr. Robert Kidston the Murchison Medal as a mark of its appreciation of his numerous and valuable contributions to our knowledge of fossil plants, especially those of the Carboniferous Period. For nearly forty years he has devoted himself to an exhaustive and successful

study of the external characters of the plant-remains associated with the various coal-seams ; and in this manner he has acquired an unrivalled knowledge of the distribution of the Carboniferous flora, which has proved of fundamental importance both to the geologist and to the practical miner. I may mention, as examples of this work, his classic memoirs on the fossil plants of the Yorkshire and Staffordshire Coalfields and of Belgian Hainaut. During more recent years he has also extended his researches to various facts of structure and morphology which have a direct bearing on evolutionary problems. His memoir on the fructification of *Neuropteris heterophylla* was the first description of the seed of a Pteridosperm in direct continuity with the frond ; while his account of the microsporangia of the Pteridosperms first demonstrated the nature of the male organs in plants of this transitional group. His description of the internal structure of *Sigillaria*, and his remarkable series of memoirs, with the late Professor Gwynne-Vaughan, on the evolution of the Osmundaceæ, must also be specially mentioned.

While pursuing his researches he has continually recognized the importance of careful field-work, and has thus made a large and valuable collection of specimens, which has always been placed freely at the disposal of his fellow-palæobotanists. In transmitting this medal, please express our hope that he will treasure it not only as a token of our admiration but also of our gratitude.

Dr. Kitchin replied in the following words :—

Mr. President,—It is gratifying to be the transmitter of the Murchison Medal to one who, a Scotsman himself, has laboured so long and so assiduously in elucidating the stratigraphical bearings of the Carboniferous flora. Dr. Kidston, I feel sure, would have received this medal with enhanced pleasure, could he have listened to your graceful and appreciative references to his work. He asks me to express to you his great regret that he is unable to be here in person ; and I may add that he is detained by responsible public duties, which have the first claim upon his time.

Dr. Kidston writes : "Will you please express to the President my sorrow at not being able to be present to thank the Society personally for the honour that they have done me in presenting me with the Murchison Medal, an honour which, it is needless for me to say, I very much value and appreciate.

"The award of this medal brings vividly to my memory that a number of years ago the Society awarded to me the Balance of the Proceeds of the Murchison Geological Fund, and I would like them to know that these proceeds were spent in the purchase of books dealing with Palæozoic Botany. It is only workers situated where not a single book on their special subject of study is obtainable for reference who can fully appreciate the value of the help that I received from that award, and I hope that the books will eventually be placed where they will be of help to others.

"I have now only to thank the Council of the Geological Society once more for its kind and encouraging recognition of my work."

In presenting the Lyell Medal to Dr. Charles William Andrews, F.R.S., the President addressed him as follows :—

Dr. ANDREWS,—The Council has awarded to you the Lyell Medal as an acknowledgment of the value of your numerous researches in Vertebrate Palæontology. Since your appointment to the Geological Department of the British Museum in 1892, you have made excellent use of the opportunities for research afforded by your official duties, and important contributions to our knowledge of fossil reptiles, birds, and mammals. You were soon attracted by the unique Leeds Collection of Oxfordian marine reptiles, and your studies of this collection eventually culminated in the two handsome volumes of the Descriptive Catalogue, published by the Trustees of the British Museum (1910–13), which must always remain a standard work on Ichthyopterygia, Sauropterygia, and Crocodilia. Your papers on the South American Stereornithes, on Rails from islands in the Southern Seas, and on *Prophaëthon* from the London Clay, are equally valuable contributions to our knowledge of extinct birds.

Your researches on the fossil mammals of Egypt, many of them discovered by yourself, are still more noteworthy; and your Descriptive Catalogue of the Tertiary Vertebrata of the Fayûm (Egypt), published by the Trustees of the British Museum in 1906, began a new era in the history of mammalian life. Your demonstration of the stages in the evolution of the Proboscidea and of the relationship between the Proboscidea and the Sirenia, your description and interpretation of the strange Eocene genus *Arsinoitherium*, and your recognition of the early differentiation of the Hyracoids in Africa are especially fundamental contributions to biological and geological science. I would further add that all your writings are characterized by remarkable thoroughness and insight into the meaning of the facts described.

As your colleague in the British Museum during the whole period of your service, it gives me great pleasure to hand to you this medal, which the Council of the Geological Society could not have more worthily bestowed.

Dr. Andrews replied in the following words:—

Mr. President,—I wish to express my most sincere thanks to the Council of the Geological Society for the honour that it has done me in awarding to me the Lyell Medal, and to you, sir, for the too flattering terms in which you have made the presentation. I am particularly pleased to have received this medal from the hands of one with whom I have been associated for so many years. You will remember that, exactly twenty years ago, you yourself received this award from Dr. Henry Woodward, and that at the same time I received a moiety of the Balance of the Proceeds of the Lyell Geological Fund.

If I have been able to accomplish something in Vertebrate Palæontology, it is mainly due to the fortunate environment in which I have found myself. An assistant in the British Museum possesses quite exceptional advantages, having free access to the great libraries and to the ever-increasing collections, and lastly, but by no means least, having many opportunities of making the personal acquaintance of workers interested in his subject. Having enjoyed these privileges, I feel that I have somewhat fallen short of what I ought to have accomplished; but, although it is just now uncertain what the future may have in store for us, I hope that I may still have opportunities of doing further work such as will justify this award.

The President then handed the Balance of the Proceeds of the Wollaston Donation Fund, awarded to Mr. William Bourke Wright, B.A., to Mr. George William Lamplugh, F.R.S., for transmission to the recipient, addressing him as follows:—

Mr. Lamplugh,—The Balance of the Proceeds of the Wollaston Donation Fund is awarded to Mr. William Bourke Wright, in recognition of his contributions to Quaternary Geology. After completing his geological studies under Professor J. Joly at Dublin University, Mr. Wright joined the Irish branch of the Geological Survey, and came under the influence of yourself when you were engaged in working out the glacial problems of the Dublin district. He took part in the revision of the memoirs and drift-maps of the Dublin, Belfast, and Cork districts, and shared with Mr. H. B. Maufe the discovery of a continuous raised-beach feature older than the Glacial Period. He also observed this pre-Glacial rock-shelf or beach in the West of Scotland, showing that a general subsidence allowed the sea to enter the valleys along the coasts of the British Isles, almost at the present sea-level, before they were occupied by the ice. After some experience both in Scotland and in England, Mr. Wright returned to Ireland, where, as senior Geologist of the Irish Survey, he has since been successfully engaged on the glacial geology of the Kenmare and Killarney district. Much of his leisure has been devoted to the preparation of an important work on *The Quaternary Ice Age*, in which he has made good use of his observations not only in the British Isles but also in Scandinavia. Impressed by the value of Mr. Wright's researches, the Council will be glad if you will transmit this award to him, with its best wishes for the progress of the work which he has so well begun.

In handing the Balance of the Proceeds of the Murchison Geological Fund, awarded to Mr. George Walter Tyrrell, F.G.S., to Dr. Herbert Lapworth, Sec. G.S., for transmission to the recipient, the President addressed him in the following words:—

Dr. LAPWORTH,—The Balance of the Proceeds of the Murchison Fund has been awarded to Mr. G. W. Tyrrell in recognition of his contributions to the petrology of South-Western Scotland. His keen petrographic insight was first shown in his description of the quartz-dolerite sills of Kilsyth. His results of most general interest to geologists are those connected with the Palæozoic alkaline rocks; for his investigation of Lugarite has added to petrology a peculiar rock-species and important evidence in favour of the differentiation of igneous rocks by the sinking of their heavier constituents. In several papers on the Auchineden Hills he has described their igneous rocks and their glacial and physical features; and in his recent account of the ravine known as the Whangie he has advanced conclusive evidence of its formation by earth-movements. As the Senior Assistant in the Geological Department of Glasgow University, and later also as Lecturer on Petrology there, he has done much towards the development of that school of geology. The Council hopes that this award may encourage and assist him in further research.

The President then presented a moiety of the Balance of the Proceeds of the Lyell Geological Fund to Mr. Martin A. C. Hinton, addressing him as follows:—

Mr. HINTON,—The Council has awarded to you a moiety of the Proceeds of the Lyell Fund in recognition of your researches on the British Pleistocene Mammalia, and as an incentive to further work of the same kind. Under circumstances frequently discouraging, you have for many years devoted yourself especially to the study of the Rodentia and the Insectivora, and have obtained a remarkable knowledge of the skeleton and teeth of certain groups which are most commonly met with among fossils. In this manner you have made discoveries with an important bearing on many problems of Pleistocene geology, which you have never failed to recognize. As one who has followed your work with great interest for several years, it gives me much pleasure to hand you this award.

The President presented the other moiety of the Balance of the Proceeds of the Lyell Geological Fund to Mr. Alfred Santer Kennard, F.G.S., addressing him in the following words:—

Mr. KENNARD,—It is particularly appropriate that the second moiety of the Proceeds of the Lyell Fund should be awarded to you, who have worked so long and so successfully with Mr. Hinton at problems of Pleistocene geology in the South of England. In the leisure of a busy life you also have made yourself thoroughly acquainted with a group of fossils, the Non-marine Mollusca, which are of fundamental importance in classifying and interpreting the various deposits in which they occur. Both alone and with Mr. B. B. Woodward you have published many interesting notes and lists of such Mollusca from Pleistocene and Holocene deposits in different parts of Britain. The Council desires to acknowledge the value of this work, and I have much pleasure in handing to you a tangible expression of its good wishes.

The President thereafter proceeded to read his Anniversary Address, giving obituary notices of Count Solms-Laubach (elected a Foreign Member in 1906), René Zeiller (el. For. Memb. 1909), Edmond Rigaux (elected a Foreign Correspondent in 1893), and Michel F. Mourlon (el. For. Corresp. 1899), as also of the following Fellows: James Geikie (el. 1873), H. H. Howell (el. 1853), R. Lydekker (el. 1883, resigned 1915), C. Callaway (el. 1875, resigned 1906), A. Vaughan (el. 1900), O. A. Derby (el. 1884), W. Anderson

(el. 1899), H. Kynaston (el. 1894), W. G. Adams (el. 1865), R. Assheton (el. 1886), Hon. Robert Marsham-Townshend (el. 1859), Sir Sandford Fleming (el. 1877), F. W. Millet (el. 1900), A. Dunlop (el. 1874) G. H. Hollingsworth (el. 1879), B. Holgate (el. 1877), W. Simpson (el. 1893), J. T. Hotblack (el. 1900), H. Rofe (el. 1890), D. A. Louis (el. 1909), H. S. Bion (el. 1911), W. J. Clunies Ross (el. 1882), and others. He also referred to the death of William Rupert Jones, late Assistant Librarian.

The President then discussed the use of fossil remains of the higher vertebrates in stratigraphical geology. The study of fossil fishes, to which he had referred in his Address of 1915, raised the question as to whether animals of apparently the same family, genus, or species might not originate more than once from separate series of ancestors. The higher vertebrates, which inhabited the land, might most profitably be examined to throw light on the subject; for the land has always been subdivided into well-defined areas, isolated by seas, mountains, and deserts, so that animals in these several areas must often have developed independently for long periods. Students of shells are unanimous in recognizing what they term homœomorphy, and trace immature, mature, and senile stages in the course of every race that can be followed through successive geological formations. Vertebrate skeletons, which have much more numerous and tangible characters, and approach senility in more varied ways, should afford a clearer view of general principles.

Even among vertebrates the evidence that most concerns the geologist is not always easily interpreted. For instance, the Sparassodonta and horned tortoises of the Argentine Tertiary are so closely similar to the existing Thylacines and the fossil *Miolania* of Australia, that they are still sometimes quoted as proving the former existence of an Antarctic Continent uniting the South American and Australian regions. On the other hand, they may be merely survivors of cosmopolitan races at the two extremes of their former range, with certain inevitable (but not altogether similar) marks of senility. In making comparisons, indeed, it is no longer enough to distinguish the fundamental and merely adaptive characters of animals; it is also essential to note separately those characters which depend on the early, mature, or senile position of the particular animals in the evolving series to which they belong.

Hitherto there seems to be only one case in which we have enough materials for forming a judgment as to whether a fundamental advance may occur more than once. Mammal-like reptiles are abundant in the Permian of North America and in the Permian and Trias of South Africa and other parts of the Old World. Recent studies have shown that all specializations in the North American forms are in the direction of higher reptiles, while all those in the South African forms are in the direction of mammals. Hence, although there is evidence of two possible sources of mammals, only one appears to have produced them.

Among advances of lower degree, the origin of the monkeys or lower Anthropoidea may be considered. It is agreed that they arose from the Lemuroidea which were almost universally distributed over

the great continents at the beginning of the Tertiary era. They seem to have evolved separately in America and in the Old World, but the two series are very sharply distinguished, although they form one zoological 'sub-order'. When isolated on the island of Madagascar, some of the same animals acquired a few peculiarities of the American, others of the Old World Anthropoidea, but never really advanced beyond the Lemuroid stage, merely becoming senile just before their extinction. Hence, the Lemuroidea evolved in three different ways, and the resulting groups are very easily distinguished.

The study of the Tertiary Ungulata is especially important, because most of the groups arose either in North America or in the Old World, which were united and separated several times. It seems clear that, although each group probably originated but once in one particular area, its members soon diverged into several independently evolving series, each imbued with some definite impulse or momentum towards specialization in the same way in the course of geological time, only at different rates. There were thus, for example, several distinct lines of horses and rhinoceroses, but all from the same source.

It is now well known that the characteristic South American Tertiary Ungulates arose in an isolated area, and many of their specializations are curiously similar to some of those observed among European Eocene and Oligocene Ungulata which soon proved abortive or 'inadaptive'. They are, however, by no means identical.

While so many changes have occurred during the evolution of the vertebrates, the persistence of characters and the strength of heredity in numerous cases are still as perplexing as they were when Huxley first directed special attention to 'persistent types'. The President enumerated some illustrations.

The ballot for the Officers and Council was taken, and the following were declared duly elected for the ensuing year:—

OFFICERS (who are also *ex-officio* members of the Council): *President:* Alfred Harker, M.A., LL.D., F.R.S. *Vice-Presidents:* Sir Thomas Henry Holland, K.C.I.E., D.Sc., F.R.S.; Edwin Tulley Newton, F.R.S.; the Rev. Henry Hoyte Winwood, M.A.; and Arthur Smith Woodward, LL.D, F.R.S. *Secretaries:* Herbert Henry Thomas, M.A., Sc.D.; and Herbert Lapworth, D.Sc., M.Inst.C.E. *Foreign Secretary:* Sir Archibald Geikie, O.M., K.C.B., D.C.L., LL.D., Sc.D., F.R.S. *Treasurer:* Bedford McNeill, Assoc. R.S.M.

COUNCIL: Henry Bury, M.A., F.L.S.; Professor John Cadman, C.M.G., D.Sc., M.Inst.C.E.; Professor Charles Gilbert Cullis, D.Sc.; R. Mountford Deeley, M.Inst.C.E.; Professor William George Fearnsides, M.A.; Walcot Gibson, D.Sc.; Finlay Lorimer Kitchin, M.A., Ph.D.; John Edward Marr, M.A., Sc.D., F.R.S.; Richard Dixon Oldham, F.R.S.; Robert Heron Rastall, M.A.; Professor Thomas Franklin Sibly, D.Sc.; Professor William Johnson Sollas, M.A., Sc.D., LL.D., F.R.S.; J. J. Harris Teall, M.A., D.Sc., LL.D., F.R.S.; William Whitaker, B.A., F.R.S.

II.—EDINBURGH GEOLOGICAL SOCIETY.

February 16, 1916.—Dr. Robert Campbell, President, in the Chair.

"Some Obscure Factors in Coastal Changes." By Professor Thomas J. Jehu, M.A., M.D., F.R.S.E., F.G.S.

Factors affecting the development of the coastline were considered under three headings—(1) Changes in the relative level of land and

sea;*(2) erosion; and (3) accretion. Since Neolithic man arrived in Britain, there is evidence of a submergence along the coasts of England and Wales and the South of Ireland, and of an emergence along the coasts of Scotland and the North of Ireland. These movements took place prior to the time of the Roman occupation of Britain. Whether movements have taken place in still more recent times is somewhat doubtful, but there are slight indications of a subsidence in the extreme North of Scotland, and at one or two places on the coasts of England and Wales. Reference was made to the need of systematic observations being carried out by the Ordnance Survey to ascertain whether such movements are now in progress, and, if so, to what extent.

Estimates were given as to the extent of erosion and accretion in the United Kingdom within recent years, and it was shown that more land had been gained by accretion and artificial reclamation than has been lost by erosion. But while the gain has been almost entirely in tidal estuaries, the loss has been on the open coasts. Further, the gains have been due not so much to the accumulation of material eroded by the sea as to the deposition of sediment brought down by rivers from their drainage areas.

The serious erosion on the coasts of Holderness and of East Anglia were described and illustrated by views. While the chief agents of erosion are well understood, it was pointed out that there is a great lack of knowledge as to what takes place below the level of low water. Observations are needed regarding such questions as submarine erosion, the travel of material below the low-water line, and the movements of outlying sandbanks. There is much obscurity as to the limits of depth at which materials are moved on the floor of the submerged continental platform by waves of current action, or both combined; and again as to what depth the movement of detritus on the sea-floor is really effective in producing abrasion. The intermittent character of the erosion at many places on the east coast of England was noted as a puzzling fact. It may be due to an alteration in the point of attack of the sea on the coastline, brought about by the shifting of outlying sandbanks or shoals.

Another factor in erosion, the importance of which has been overlooked, is the action of rock-boring organisms. An account was given of the present state of knowledge regarding their work and of their effect on the sea-bed near Cromer. Little is known as yet as to the rate of boring, or as to the depth to which it occurs.

CORRESPONDENCE.

DIFFERENTIATION IN IGNEOUS ROCKS.

Sir,—Having occasion to refer to the report of my contribution to the discussion "Sur la différentiation dans les magmas ignés" at the Toronto Geological Congress, in the *Compte Rendu* (pp. 248–9), I find that through some typographical accident, which in the absence of a proof remained uncorrected, the meaning of one paragraph has been seriously obscured.

After suggesting that the presence of a considerable amount of water in a magma might result in its separation in the liquid state into two immiscible portions, the lighter containing the greater part of the water and of the more acid and alkaline constituents, representing quartz and the alkali felspars, and the heavier consisting mainly of the basic constituents with comparatively little water, I continued: "It was to be expected that the character of the differentiation would depend on the amount of water present. If this were larger, one would expect a comparatively complete removal of the alkali felspar materials." ["With less water one may expect a greater amount of the alkaline material to remain with the more basic portion"], "and with further differentiation by other processes this would naturally give rise to a series of rocks of the alkali or 'Atlantic' type. This suggestion—it was intended to be nothing more—appeared to derive some support from the frequent association of rocks of this character with block faulting, while rocks of the normal or 'Pacific' type were usually found within areas characterized by folding, where there was less facility for the escape of water to the surface."

The words in square brackets are those actually used in the first draft of the summary of my remarks supplied to the Secretary of the Congress. They were probably modified in the fair copy, but those appearing in their place in the printed text do not make sense. Indeed, the only meaning that might be extracted from them would be exactly the opposite of that intended, as shown by the context. A brief but correct version will, however, be found in my contribution to the discussion on a paper by Professor P. Marshall (Quart. Journ. Geol. Soc., vol. lxx, p. 406, 1914).

It is immaterial for the present purpose whether my suggestion with regard to the origin and distribution of the alkali rocks was well founded. I merely wish to have it correctly recorded.

J. W. Evans.

Imperial College of Science and Technology
(Royal School of Mines).

March 9, 1916.

OBITUARY.

PROFESSOR JOHN WESLEY JUDD.

Many friends and numerous old pupils will deeply regret the death of Professor J. W. Judd, who passed away at his home in Kew on March 3. In 1905, when he retired from the Chair of Geology in the Royal College of Science, this Magazine published the story of his life, with a list of his many contributions to science, so that it will now suffice to continue that story to the closing days. These were spent either at Kew or at a small house which he had acquired at Walmer; for he had ceased to travel, partly on account of his own health, since before retirement he had begun to suffer from a form of

deafness which is often associated with vertigo, and partly because that of one of his two children required constant watchfulness. His own physical trouble, which happily did not materially increase, was just sufficient to cause his gradual disappearance from scientific gatherings in London. Still, he was my guest in Cambridge at the Darwin Celebration in 1909, and it was not till the outbreak of the present War that any serious failure became marked. Of that War he may be regarded as an indirect victim. Its horrors at the present and its ominous promises for the future were a bitter disappointment to a man of his sympathetic nature. The thought of them depressed his spirit by day and haunted his dreams by night. Rather more than a year ago he began to suffer much from neuritic pains, which often cramped his limbs and impeded his movements. A visit to Walmer during last summer sent him back to Kew in a more hopeful condition, but no long time afterwards he began steadily to lose strength, till at last he literally fell asleep.

I can heartily endorse every word that a writer in this Magazine has already said in Judd's praise as a geologist and a friend, alike to those of his own standing and to his pupils; for I have known him intimately for some forty years. We were Joint Secretaries to the Geological Society from 1878 to 1884, and he continued his services while I was President. We have met on many committees and as fellow-examiners, and in matters connected with the Funafuti boring, where he did a heavy piece of work in connexion with the examination and transport of the cores. We did not always quite agree on geological questions and matters of policy, but that never affected the constancy of his friendship. More than once he has gone out of his way to do me valuable service, and I have never met with a man who was less of a self-advertiser and self-seeker, or was more considerate of others. He was inflexible in taking the course to which, in his opinion, duty pointed, but his quiet, almost imperturbable, manner was united with a truly warm heart.

Though during the last ten years new investigations had become practically impossible, he still made valuable contributions to geological literature. The most important of these, for it is needless to enumerate every "chip from his workshop", were the following: "Henry Clifton Sorby and the Birth of Microscopic Petrology" (this Magazine, 1908, p. 193); "Darwin and Geology," an essay in *Darwin and Modern Science* (1909); *The Coming of Evolution*, published in the Cambridge Manuals of Science and Literature (1910); *The Students' Lyell*, his second, revised and enlarged edition of Lyell's *Students' Elements of Geology* (1911); and an obituary of Sir Joseph Dalton Hooker, contributed to Professor Watts' Presidential Address to the Geological Society in February, 1912. Judd's last communication to that Society was on March 25, 1914, when he gave a succinct account of the Island of Rockall as a preface to a paper on its unusual rock by Dr. H. S. Washington. All these maintained a high level, and the *Coming of Evolution* is a most attractive book, both from the writer's intimacy with Darwin and the "dauntless three" who stood beside him in that conflict and from its remarkable literary grace.